

PNNL-37799

Core Model Proposal 401

Ukraine as an Independent Region

June 2025

Hassan Niazi
Roan P. Chadsey
Ying Zhang
Anastasiia Zagoruichyk
Pralit L. Patel
Nazar Kholod

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor Battelle Memorial Institute, nor any of their employees, makes **any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights.** Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof, or Battelle Memorial Institute. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

PACIFIC NORTHWEST NATIONAL LABORATORY
operated by
BATTELLE
for the
UNITED STATES DEPARTMENT OF ENERGY
under Contract DE-AC05-76RL01830

Printed in the United States of America

Available to DOE and DOE contractors from
the Office of Scientific and Technical Information,
P.O. Box 62, Oak Ridge, TN 37831-0062

www.osti.gov
ph: (865) 576-8401
fox: (865) 576-5728
email: reports@osti.gov

Available to the public from the National Technical Information Service
5301 Shawnee Rd., Alexandria, VA 22312
ph: (800) 553-NTIS (6847)
or (703) 605-6000
email: info@ntis.gov
Online ordering: <http://www.ntis.gov>

Core Model Proposal 401: Ukraine as an independent region

Product: Global Change Analysis Model (GCAM)

Institution: Joint Global Change Research Institute (JGCRI)

Authors: Hassan Niazi, Roan Chadsey, Ying Zhang, Anastasiia Zagoruichyk, Pralit Patel,
Nazar Kholod

Reviewers: Ellie Lochner, Neal Graham, Maridee Weber

Date committed: May 22, 2025

IR document number: PNNL-37799

Related sector: Ukraine, socioeconomics, energy, water, agriculture, emissions

Type of development: Data

Purpose: The goal of this core model proposal (CMP) is to break out Ukraine from the Europe_Eastern region. This work aims to establish Ukraine as an independent region in the GCAM core (region 14) while moving Belarus and Moldova to region 15 (Europe_Non_EU).

Description of Changes

Summary of Changes

In most cases, current model assumptions have been maintained. However, there are cases where underlying data has been updated to reflect region-specific trends as well as to maintain consistency with the rest of the model e.g., income shares currently used for multiple consumers of energy in the building sector.

This proposal presents changes to the codebase and updates to raw input data. The following is a high-level, non-exhaustive summary of changes presented in this CMP. We have:

- Updated several mappings to recode region 14 (formerly *Europe_Eastern*) as Ukraine and moved Belarus and Moldova to region 15 (*Europe_Non_EU*).
- Updated several assumptions in the raw data files which provide information by region to reframe Ukraine as the 14th region, including coefficients, base year values, share weight interpolation values and rules, pipeline networks for gas trade, elasticities, shares, etc.
- Changed documentation and in-code comments at several places referring to fixed 32 regions in GCAM to indicate that GCAM can have any number of regions (zwater_L110.water_demand_primary.R).
- Updated code base in gcamdata to dynamically process data for Ukraine given special cases (e.g., zenenergy_L2231.wind_update.R).

A detailed item-by-item summary of changes can be found in Table # 1 below.

Table 1: Summary of the code and data changes in this CMP for the Ukraine breakout

#	Object	Change
	csv/objects/build/vc10	
1	objects.vcxproj	change visual studio platform tools version to be consistent with hector's toolset and avoid error in compiling locally on windows
	input/gcamdata	
	data	
2	PREBUILT_DATA.rda	binary file, reflects updates from processed proprietary data
	inst/extdata	
	aglu	
3	A_bio_frac_prod_R.csv	added base-year residue biomass fraction assumptions for Ukraine, kept same as previous region (14)

4	A_biomassSupplyShare_R.csv	added biomass supply-side share weight assumptions for Ukraine (High), kept same as previous region (14)
5	A_soil_time_scale_R.csv	added 50 years as the number of years for soil carbon to recover from land-use change for Ukraine (same as previous region # 14)
	common	
5	GCAM_region_names.csv	replaced Europe_Eastern with Ukraine as the 14th region in the mapping file
6	iso_GCAM_regID.csv	changed Belarus and Moldova's mapping from region 14 to region 15
	emissions	
8	A_regions.csv	added coefficient for nitrous oxide emissions from bioenergy production, kept same as previous region (14)
9	EPA_country_map.csv	changed Belarus and Moldova's EPA country mapping from region 14 to region 15
	energy	
	mappings	
10	WSA_gcam_mapping.csv	changed Belarus and Moldova's world steel association country mapping from region 14 to region 15
11	A_regions.csv	specified biodiesel (Oil Crop) technology change parameters for Ukraine, same as region 14
12	A22.SubsectorInterp_en_R.csv	added biomass liquid shareweight interpolation function for Ukraine, same as region 14
13	A22.SubsectorShrwtFlt_en_R.csv	added biomass liquid shareweight interpolation value for Ukraine, same as region 14

14	A23.subsector_interp_R.csv	added shareweight interpolation function for electricity from refined liquids for Ukraine, same as region 14. Missing values, assumed to be NAs, were indeed explicitly changed to NA
15	A44.CalPrice_bld.csv	updated building services prices that are used to calibrate satiation impedance from the latest GCAM run that includes Ukraine
16	A328.energy_infill_model_intercepts_R.csv	added food processing energy use infilling intercepts for Ukraine, same as region 14
17	A328.regionaltech_cost.csv	added food processing costs for Ukraine, same as region 14
18	GCAM_region_pipeline_bloc_export.csv	specified Ukraine's pipeline gas exports to Russia, same as region 14
19	GCAM_region_pipeline_bloc_import.csv	specified Ukraine's pipeline gas imports from Russia and European bloc, same as region 14
20	offshore_wind_potential_scaler.csv	added offshore wind resource potential scaling factor for Ukraine, same as region 14
	socioeconomics	
	GTAP	
21	GCAM_GTAP_region_mapping.csv	replaced Europe_Eastern with Ukraine as the 14th region in the mapping file and changed Belarus and Moldova's mapping from region 14 to region 15
22	A323.inc_elas_parameter.csv	added parameters to calculate iron and steel income elasticity per capita steel, same as region 14
23	A326.inc_elas_parameter.csv	added parameters to calculate aluminum income elasticity per capita steel, same as region 14

24	income_shares_quintiles.csv	deleted the income shares by quintiles file because it is not used in the data system and could be aggregated from the income shares by deciles in the code by using respective deciles e.g., $q1 = f(d1, d2)$
25	income_shares.csv	updated income shares by deciles for Ukraine and Europe_Eastern. Re-ran pridr to generate disaggregated income deciles for Ukraine region 14, only used the default PCA algorithm (Two Components) model because that is used in the current model, only updated the shares, and assigned zero to all other columns (e.g., gini, GDP per capita), which weren't used in the data system anyway
	water	
26	groundwater_uniform.csv	changed from 32 to 33 regions in the description
27	nonirrigation_consumption.csv	changed from 32 to 33 regions in the description
28	nonirrigation_withdrawal.csv	changed from 32 to 33 regions in the description
	man/	several documentation changes, regenerated .Rd files.
	R	
29	constants.R	removed the gcam.REGION_NUMBER constant as it was only used in one chunk and should be ideally generated in the code from GCAM_region_names.csv to assert the number of regions.
30	sysdata.rda	binary file, reflects updated LEVEL2_DATA_NAMES
31	zemissions_L112.ceds_ghg_en_R_S_T_Y.R	typo correction

32	zenergy_L115.roofPV.R	removed the assumption of fixed number of regions in the description
33	zenergy_L120.offshore_wind.R	added processing to make sure offshore wind estimates align with data for the remaining countries in the region. Europe_Eastern comprised Ukraine, Belarus, and Moldova, but only Ukraine contributed to offshore wind estimates of Europe_Eastern. Region 14 being changed to Ukraine has no impact on the offshore wind within the region. Also, removed the assumption of fixed number of regions in the description
34	zenergy_L144.building_det_en.R	introduced a check to ensure building service prices are updated for a newly broken out region, with some template code to help fill the values initially to produce a GCAM run. The A44.Calpric_bld.csv file is updated from a solved GCAM run. But first we need to produce a GCAM run which solves with the new regional definitions before we could update the file
35	zenergy_L144.building_det_flsp.R	shortened one code line
36	zenergy_L244.building_det.R	code robustness improvements: running inside the chunk wasn't possible, removed missing columns, shortening, prevented circularity to only add multiple consumers if the residential sector doesn't already have them, GCAM version update for the file in the comments etc

37	zenergy_L1011.fossilFuel_GrossTrade_EJ_R_C_Y.R	bugfix to allow interpolating and extrapolating for natural gas trade patterns for some combination that only had one value. More specifically, approx_fun needs at least 2 values to work, some combinations only had one value, so filling in either direction was necessary to give reference points for interpolating/extrapolating to work. Before the fix, the model resulted in natural gas trade calibration errors due to mismatched export estimates
38	zenergy_L2231.wind_update.R	added a code block to add mid.price for regions with only one price point, removed the assumption of fixed number of regions in the description
39	zenergy_L2391.gas_trade_flows.R	replace missing calibrated output value for natural gas imports and exports with zero
40	zsocio_L180.GDP_macro.R	set globally averaged capital stock values from GTAP for missing regions
41	zwater_L110.water_demand_primary.R	removed the assumption of fixed number of regions in the description
42	zwater_L202.water_resources_unlimited.R	removed the assumption of fixed number of regions in the description
43	DESCRIPTION	package file, upgraded gcamdata version to stay in sync with GCAM version
44	input/extra/renewable_shareweights_ssp1_32.xml	Recode Europe_Eastern to Ukraine for this file
45	input/policy/*	Recode Europe_Eastern to Ukraine for all policy files

Code and Data Updates

Income shares for the multiple consumers of residential building energy in the buildings sector

Income shares by decile (income_shares.csv) were updated for Ukraine. The *pridr* package was re-run to generate disaggregated deciles specifically for Ukraine. Only the default PCA algorithm with two components (*PCA algorithm (Two Components)*) was used during this process, since other models of PCA for the projection weren't used in GCAM. The update focused solely on the income shares, while all other columns, such as Gini and GDP per capita, were assigned a value of zero since they are not utilized in the data system. The income shares file by quintiles (income_shares_quintiles.csv) was deleted because it is unnecessary to maintain this file and is currently not used in the data system. If necessary, quintiles can still be calculated from the deciles within the code, for example, by aggregating deciles D1 and D2 to obtain Q1. Figure 1 shows a comparison between processed income shares in the CMP and in master by region (from *L144.income_shares* data object in *zenergy_L244.building_det.R*). The only major change is in the former *Europe_Eastern* region which is shown in the Ukraine panel as *master*.

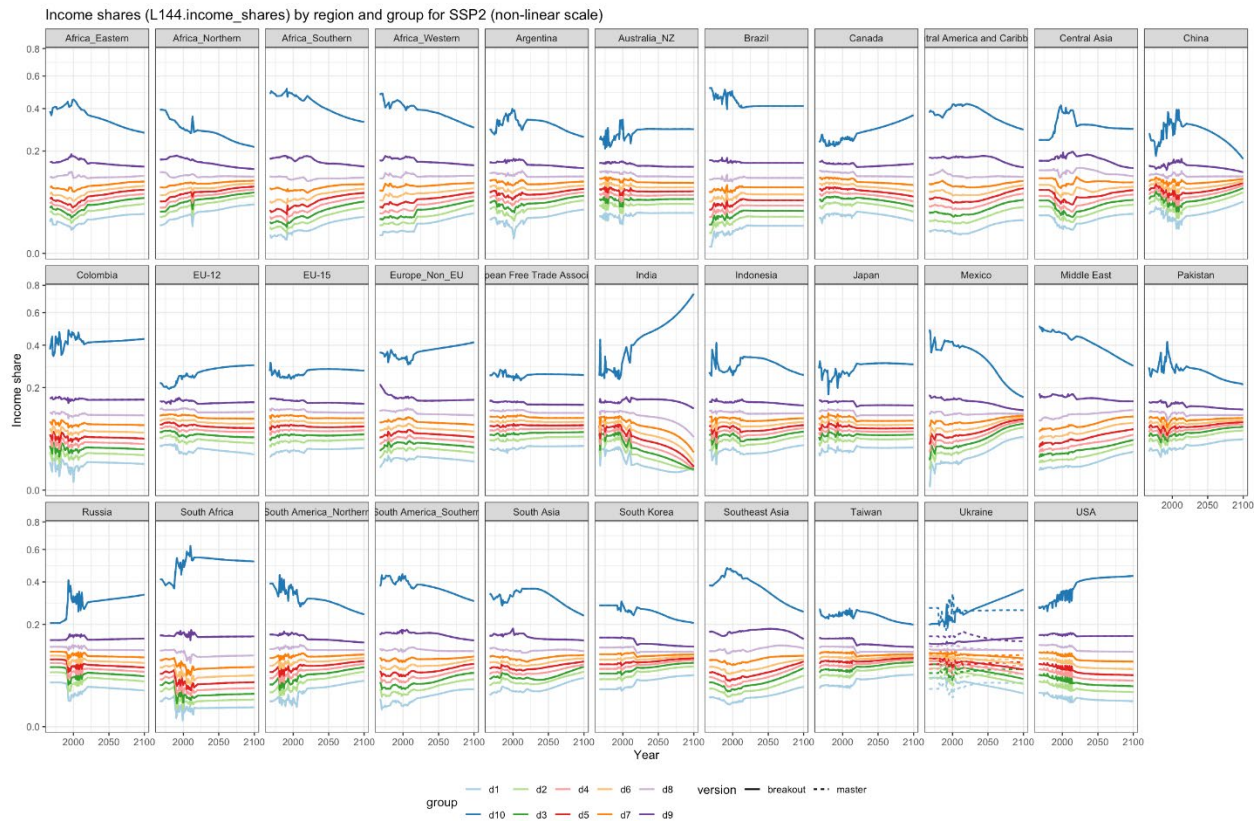


Figure 1: A comparison between processed income shares in this CMP and master by region (from *L144.income_shares* data object in *zenergy_L244.building_det.R*). Note the y-axis scale is non-linear (square root).

We also added bug fixes and improved code robustness of the chunk *zenergy_L244.building_det.R* by removing missing columns which were preventing the

renaming and selection of columns when running the code inside the chunk (in debug mode). We also prevented circularity in one of the code blocks to add multiple consumers only if the residential sector didn't already have them.

Wind and offshore wind processing

We have assigned zero offshore wind values where countries do not have offshore wind (as per *NREL_offshore_energy*) in the *zenergy_L120.offshore_wind.R* file. Additional processing has also been added to ensure that offshore wind estimates align with the data for the rest of the countries in each region. Europe_Eastern originally included Ukraine, Belarus, and Moldova, but only Ukraine contributed to the offshore wind estimates. Now that Ukraine is treated as a separate region, offshore wind for Moldova and Belarus is effectively zero and does not contribute to Europe_Non_EU as Moldova and Belarus are the land-locked countries. Consequently, we assigned zero values to offshore wind potential, capacity factor, and potential share for countries and regions in the former Europe_Eastern region that do not have offshore wind resources. In summary, the code changes identified missing regions and added to the relevant datasets with zero resource potential, mid-price, and grid costs to ensure consistency. This update ensures that there are values (even if zero) for the regions without offshore wind.

The implications for model dynamics are illustrated in in Figure 2. We also zoom in to the old *Europe_Eastern* region compared with *Ukraine* (Figure 3). The combined offshore wind generation for Ukraine and the lack of adjustment to the Europe_Non_EU region (with Moldova and Belarus) matches the old *Europe_Eastern* generation, as Moldova and Belarus alone have zero offshore wind (Figure 4).

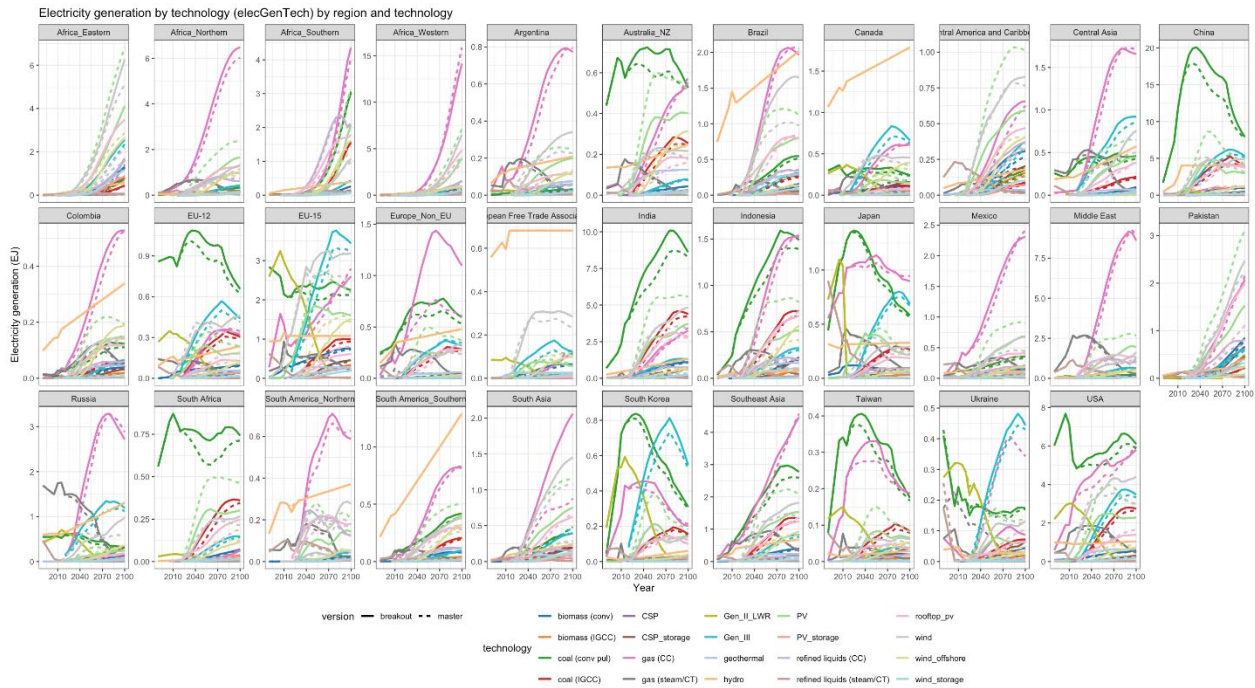


Figure 2: Comparison of electricity generation by technology across regions between master and the Ukraine-breakout version of GCAM

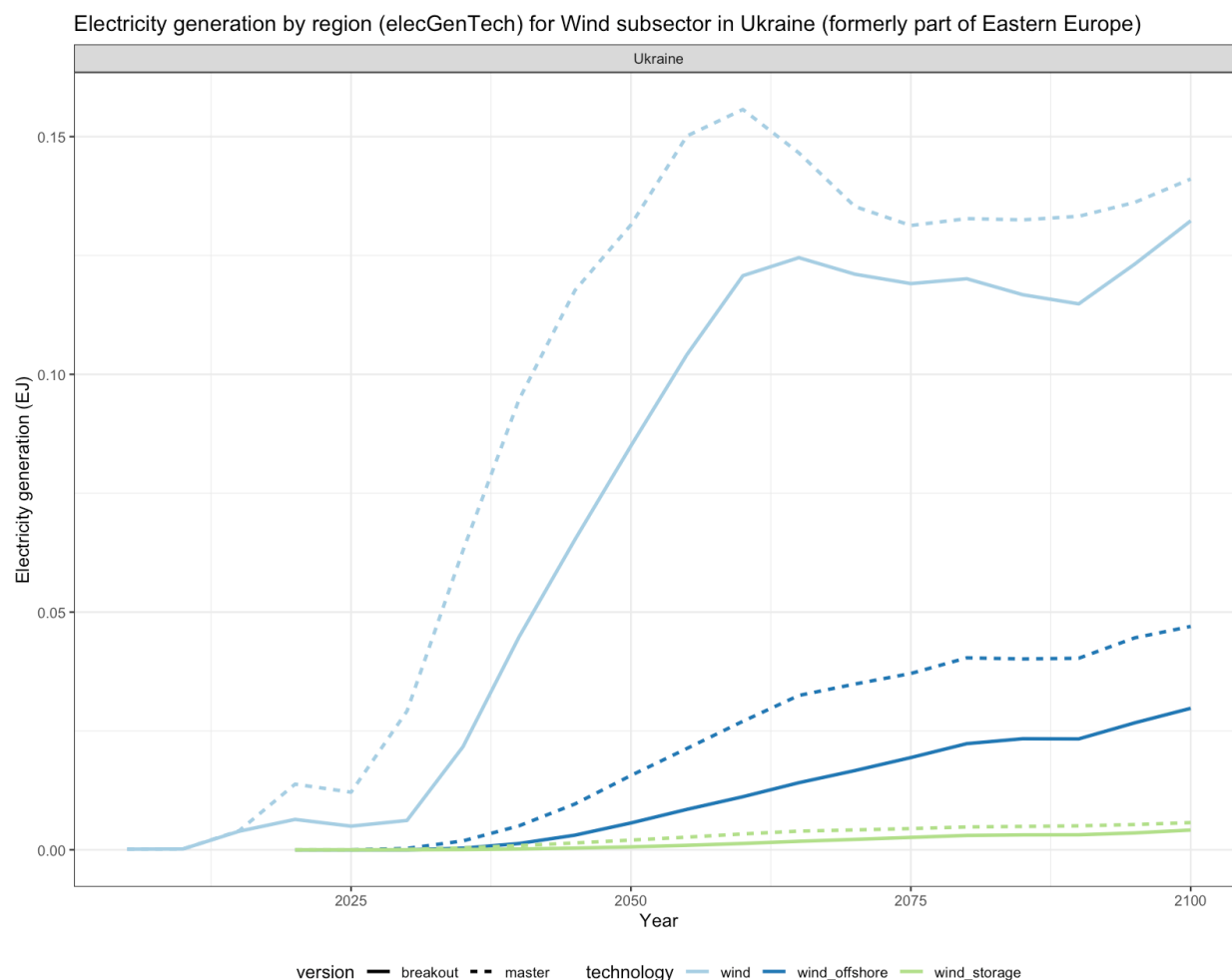


Figure 4: Electricity generation by wind technologies in old Europe_Eastern region and Ukraine. An additional figure showing wind electricity by region is included at the end of this proposal (figure 15).

An additional wind-related update includes adding a code block to add *mid.price* for regions with only one price point, and removing the assumption of a fixed number of regions in the description of `zenergy_L2231.wind_update.R`.

Building services calibrated prices

Based on the latest GCAM run with Ukraine as a separate region, we have updated the data file for building service prices (`A44.CalPrice_bld.csv`), which is used to calibrate satiation impedance for buildings. For any regional breakout, the `A44.CalPrice_bld.csv` file must be updated from the outputs of a solved GCAM run with the new regional definitions (in this case with *Ukraine* in the reference scenario run). To update this file, first, the code needs to be adapted to include arbitrary prices to allow the model to solve with the newly included region, and then use the outputs to overwrite arbitrary values with actual values from a solved GCAM run. To streamline the process of producing an initial run, we have included template code in `zenergy_L144.building_det_en.R` to help initialize values for a successful GCAM run. We

have also introduced a validation check in the same chunk to ensure that prices are included for newly defined regions. Because other changes may interact with the prices outputs, this file was updated during the final stages of preparing this pull request/CMP. Figure 5 compares building energy service prices (*L144.prices_bld*) by region and market, showing no significant changes except for *Ukraine*. The changes to the Africa regions can be attributed to a version difference between the *L144.prices_bld* input files taken from *gcam-v5.4* for master and *gcam-v7.3* for the breakout.

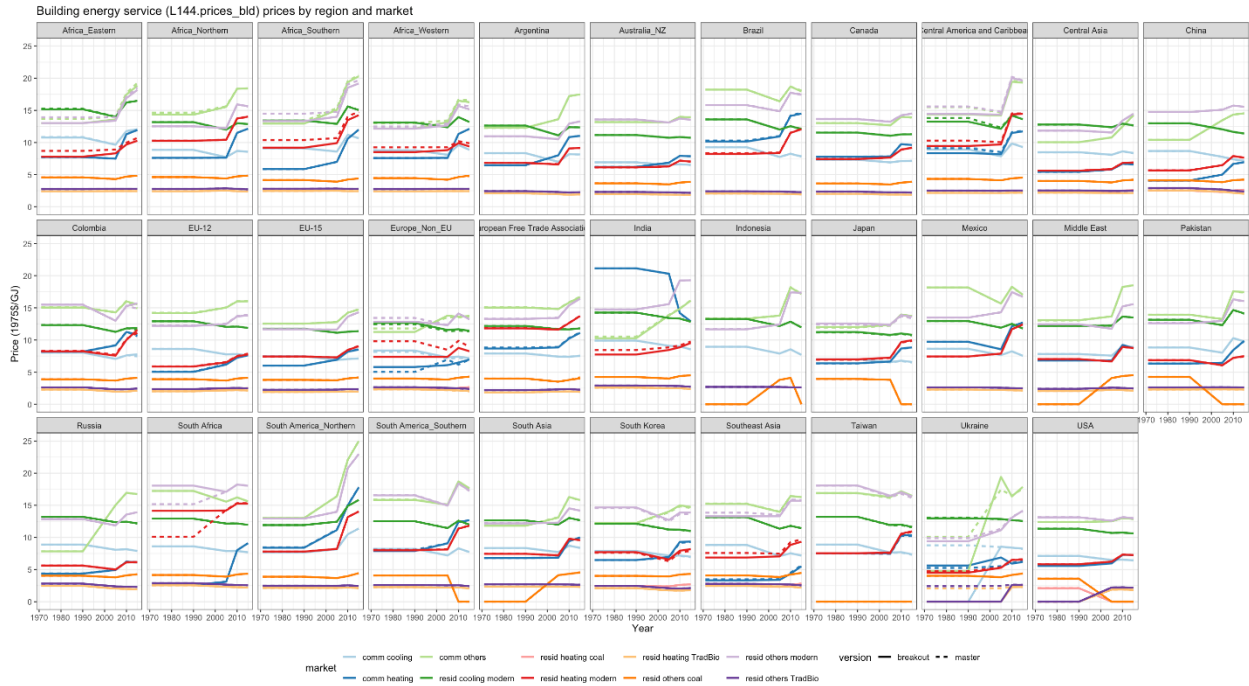


Figure 5: Building energy service prices (*L144.prices_bld*) by region and market for all GCAM regions, showing few significant changes in regions other than *Ukraine* and *Europe_Non_EU*.

Validation

All standard validation scenarios (Reference, SSPs, SSP_RCPs, USA, USA_RCP2.6) have solved (but SSP4_2p6). No significant change has been observed in the demand drivers (GDP and Population) since the underlying data was the same and the only change was the remapping of *Ukraine* from *Europe_Eastern* to its own region and of *Moldova* and *Belarus* to *Europe_Non_EU*. Despite that, the primary energy supply for most fuels, including oil, gas, biomass, and nuclear, has slightly increased in the new version compared to GCAM 7.3, with the exception of solar showing a decrease in production compared to master. Similarly, electricity generation has also slightly increased for generation technologies beginning around the middle of the century. None of these changes are significantly large. Water withdrawals for biomass-based thermoelectric cooling have increased in the new version compared to GCAM 7.3, especially for the SSP4 scenario. Global emissions and radiative forcing have remained largely unchanged. The figures below show key model dynamics for primary energy, electricity generation, land allocation, water withdrawals, radiative forcing, CO2 emissions, and non-CO2 emissions.

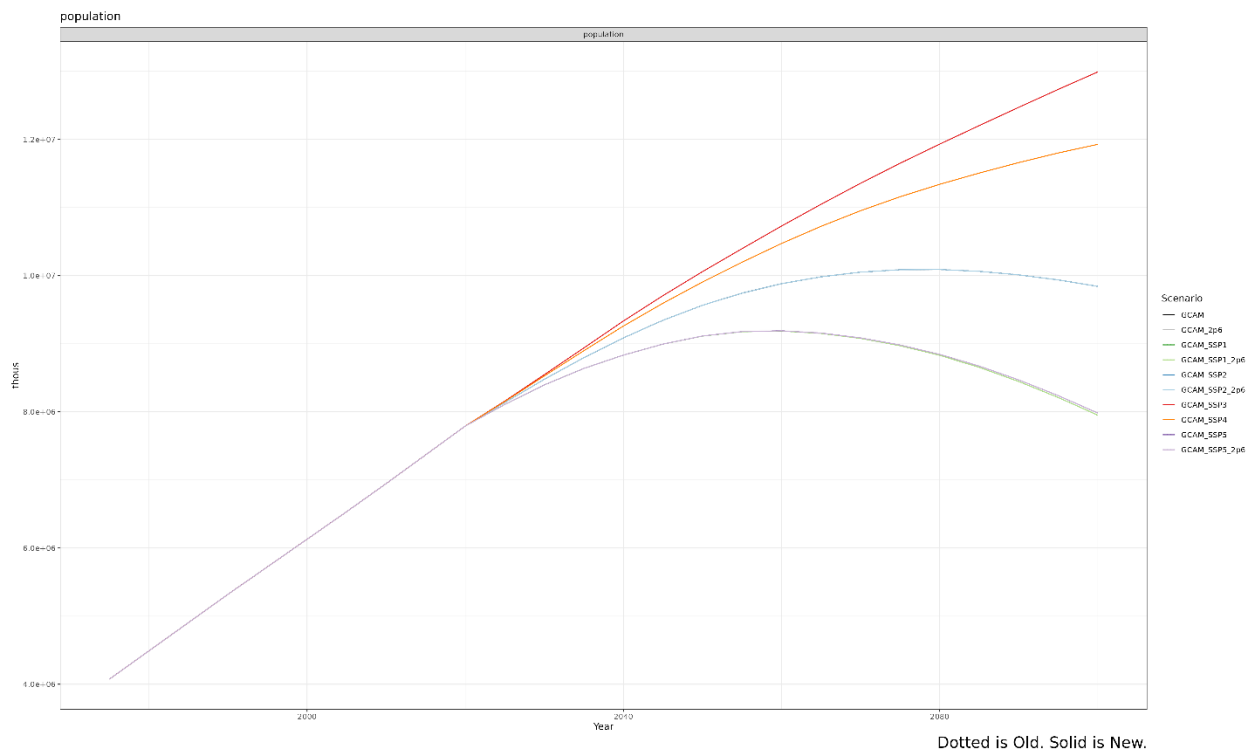
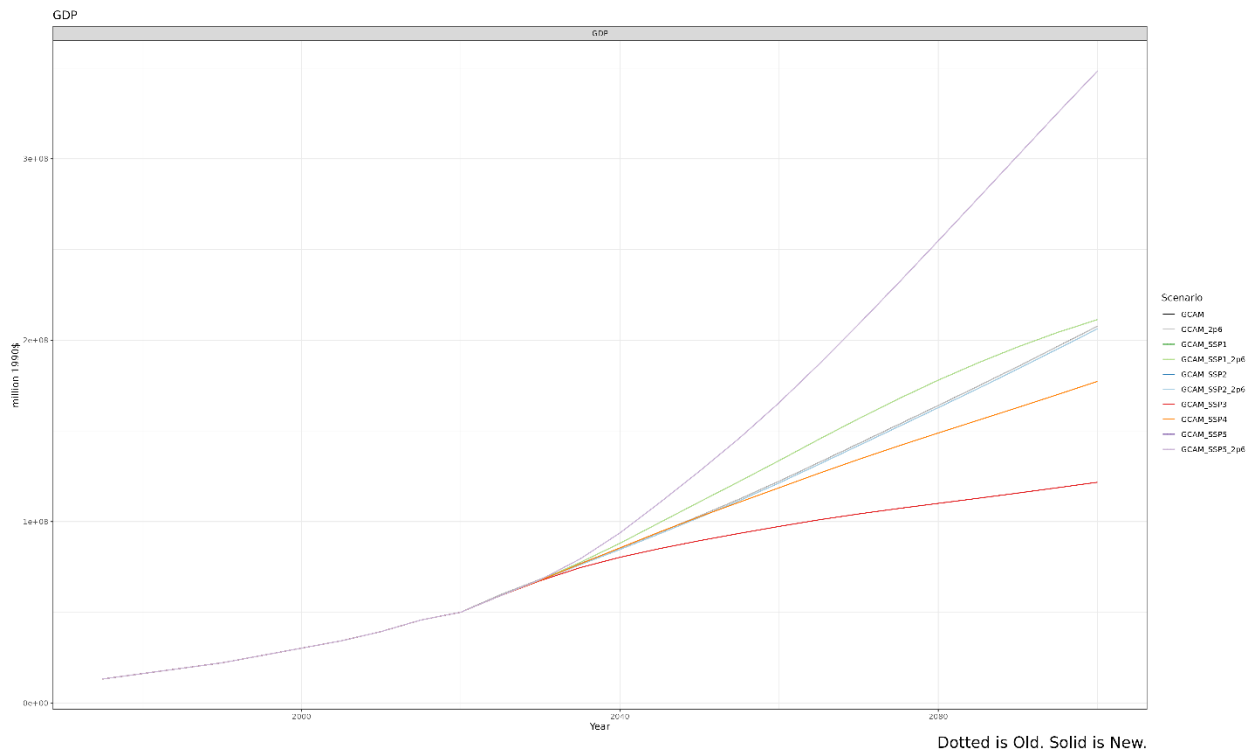


Figure 6: Population and GDP globally

Breaking out Ukraine as a new region has some effects on global trends. In the new runs (solid lines), there's generally higher global consumption of coal compared to the old runs (dotted lines), particularly at the middle of the century. This may reflect that Ukraine is likely to have a

more coal-intensive trajectory compared to the rest of Europe_Eastern given their resource base. Wind energy consumption globally is higher in new runs across most scenarios, particularly for scenarios with higher energy demand, while solar energy consumption is slightly decreased in most scenarios. This is consistent with the observation that Ukraine's potential for renewable energy resources such as offshore wind is relatively high compared to the rest of Europe_Eastern. After breaking out Ukraine, there's more incentive to exploit these resources in Ukraine and export the energy with higher prices than the prices consumed "domestically" within one aggregated Europe_Eastern region as previously modeled. Similar for nuclear, in Ukraine, nuclear is a significant part (~50%) of their energy mix in recent years.

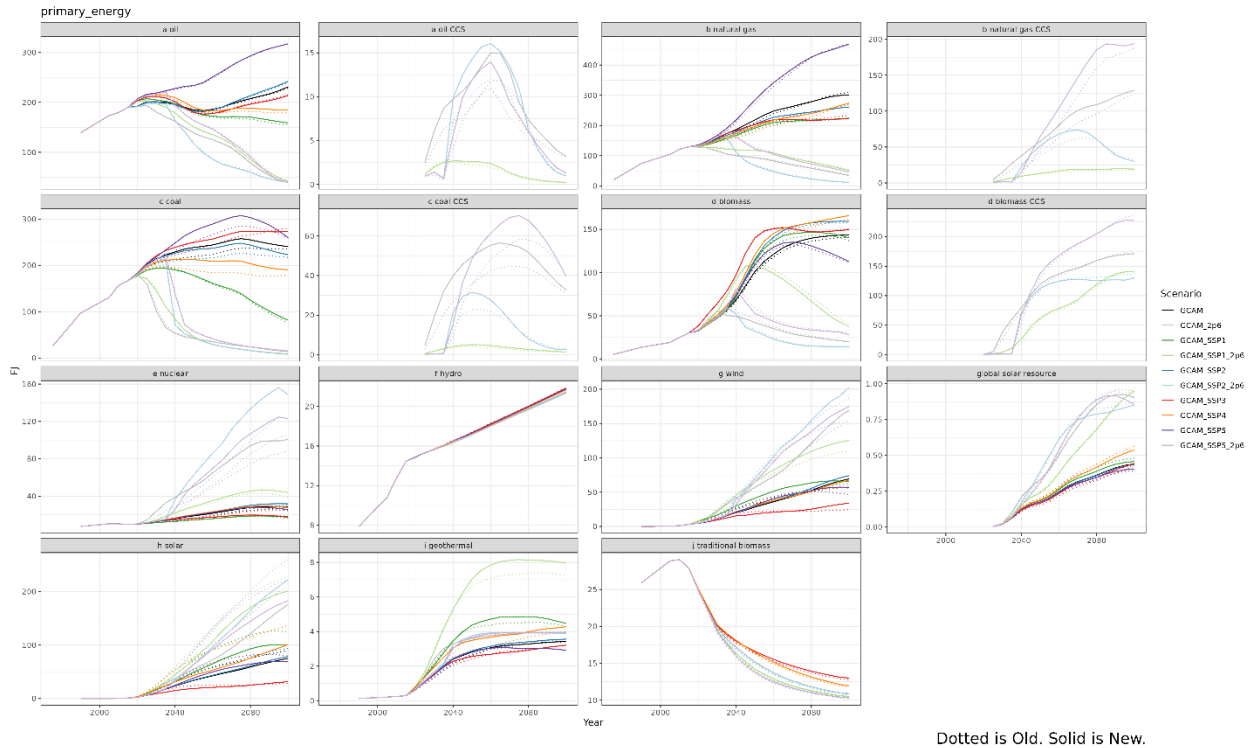


Figure 7: Primary energy usage globally

The largest difference between new and old runs is the electricity generation by wind, solar, and nuclear. The new runs show higher electricity generation from wind and nuclear than the old runs and lower generation by solar, though solar storage does increase. The reasoning is similar to the comparison of primary energy consumption discussed above. In summary, when Ukraine is modeled within an aggregated region, its wind and nuclear resources are averaged/diluted with lower resource nations, and the resources may be associated with higher resource prices after averaging. This leads to lower resource exploitation than when Ukraine is a standalone region. Additionally, as discussed above, there may be higher economic incentives for Ukraine to export the energy at higher global prices. Therefore, breaking out Ukraine captures the previously diluted resources potential, which would help better represent the levels of resource utilization, export, and consumption.

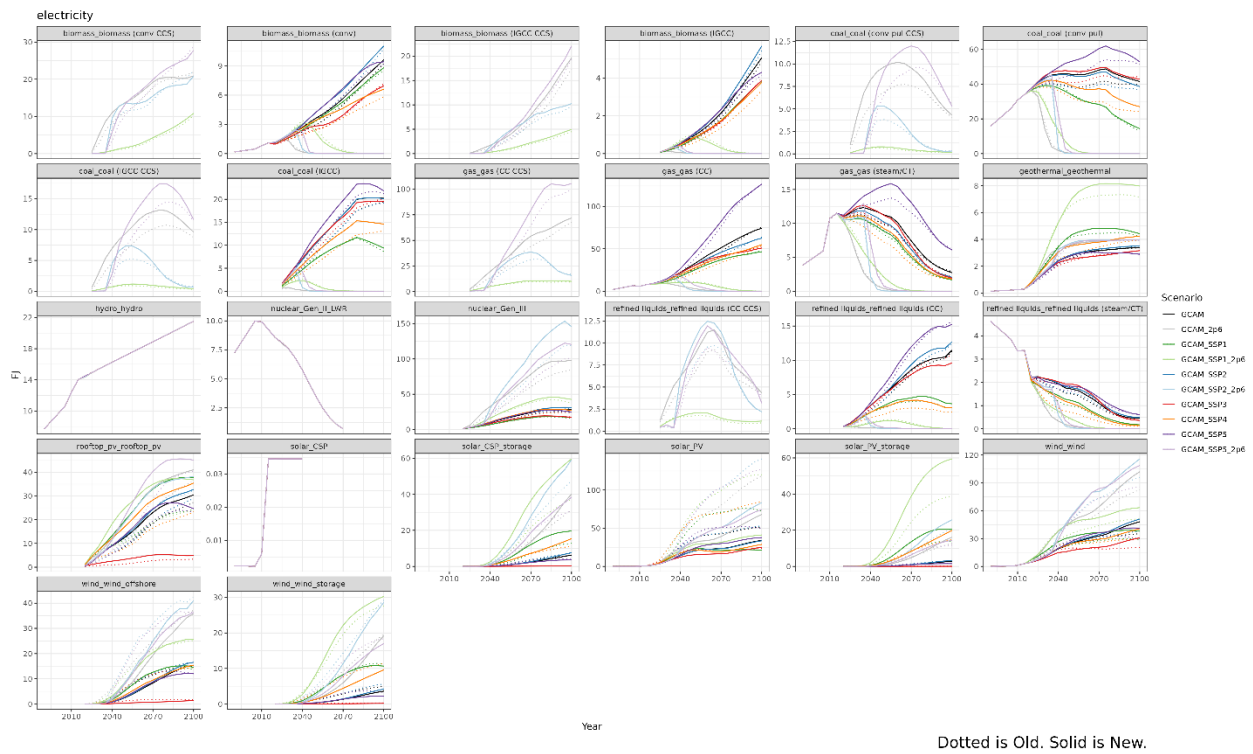
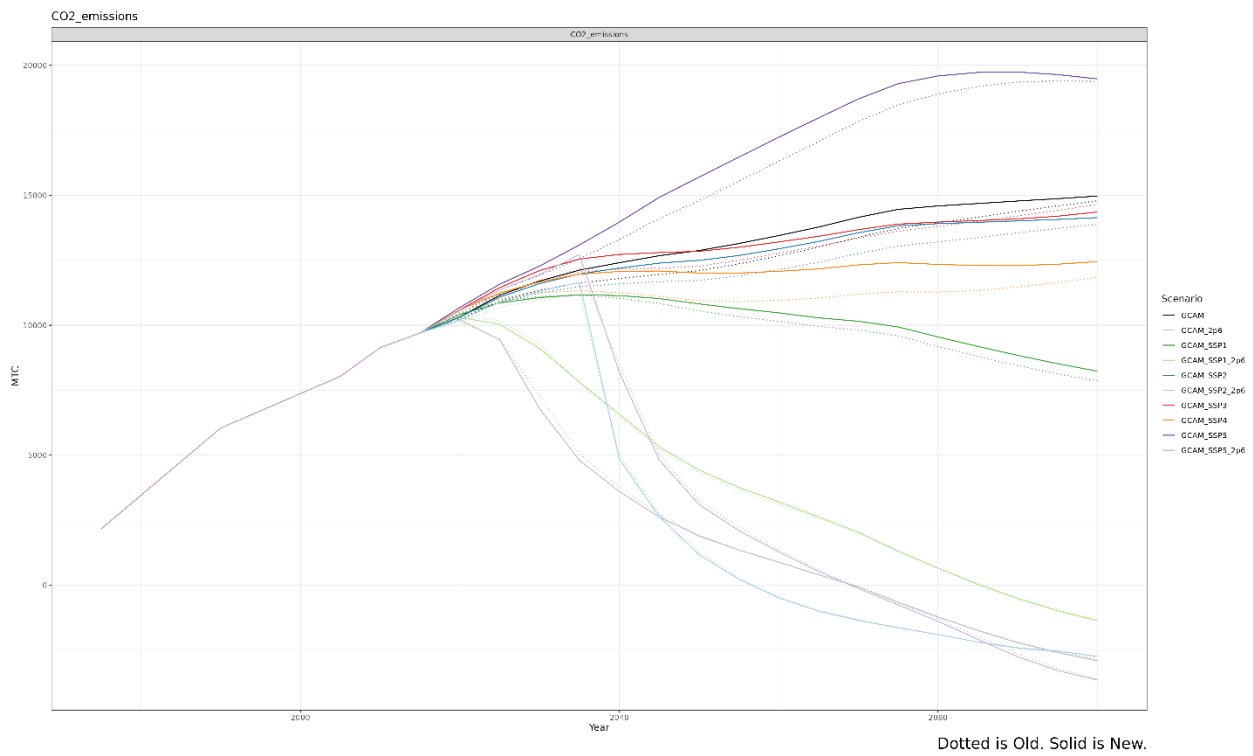


Figure 8: Electricity generation by technology globally



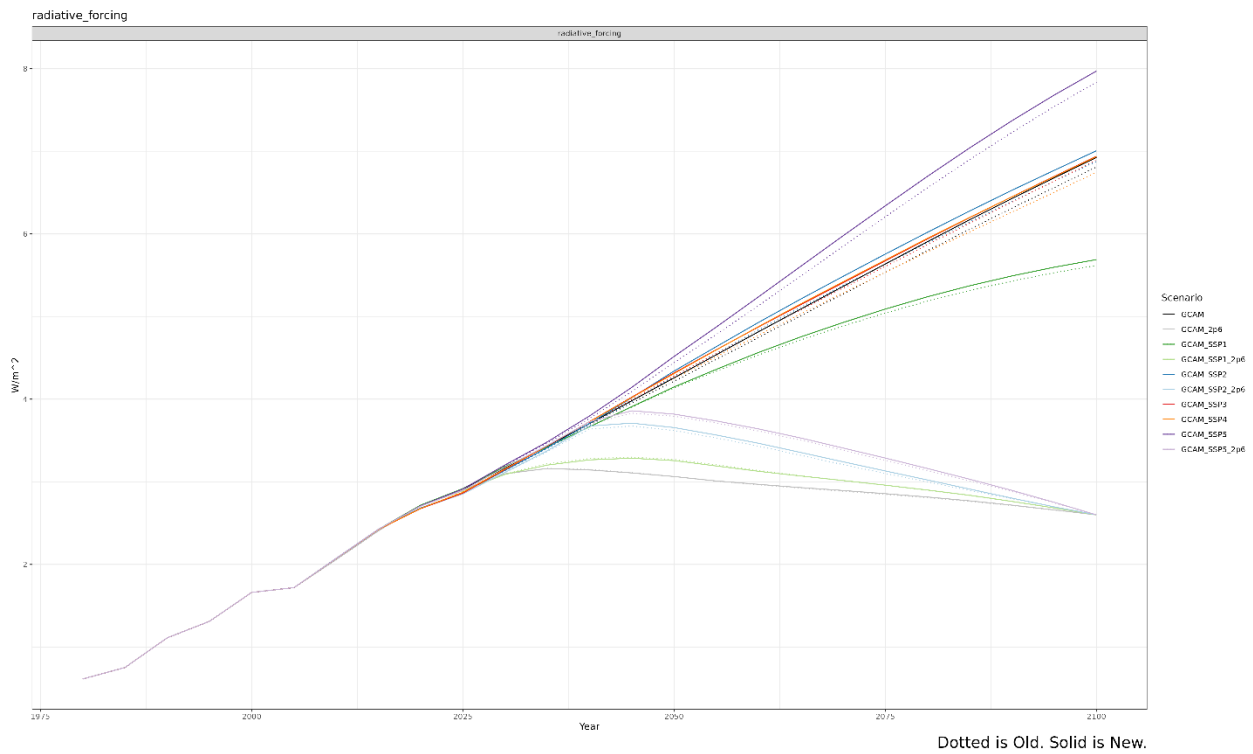


Figure 9: CO2 emissions and radiative forcing

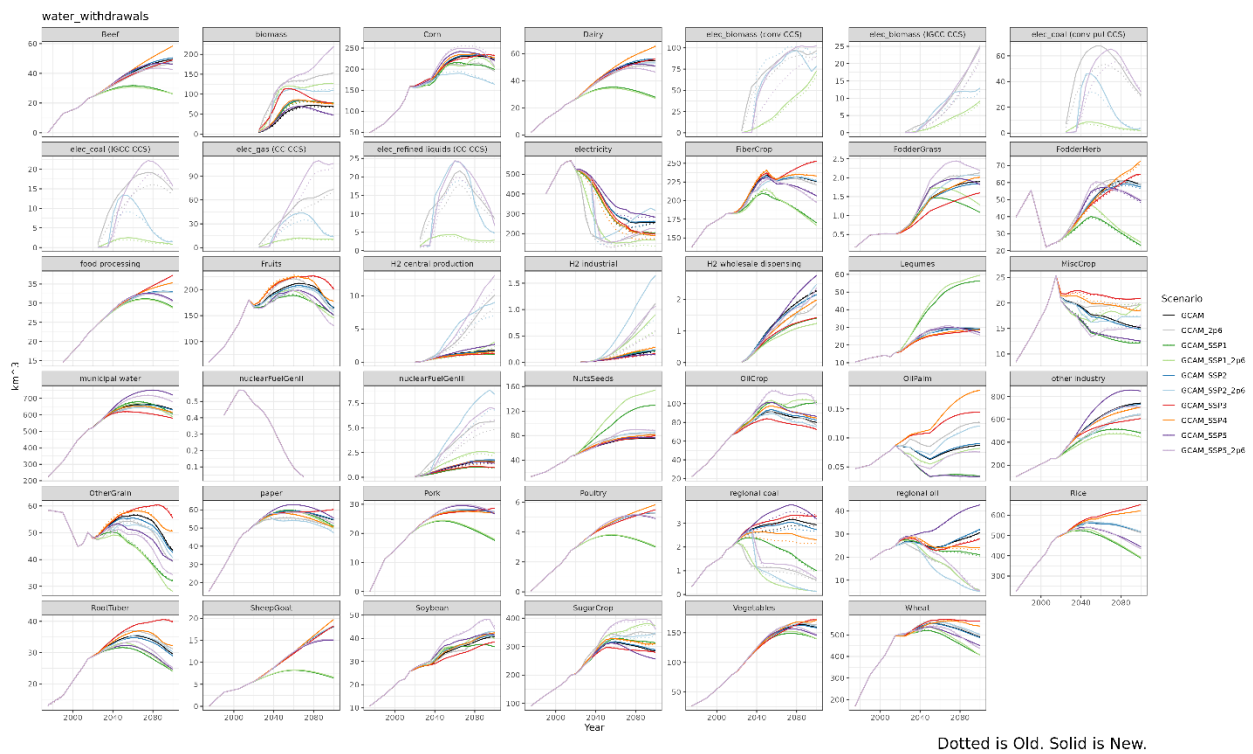


Figure 10: Water withdrawals by technology globally

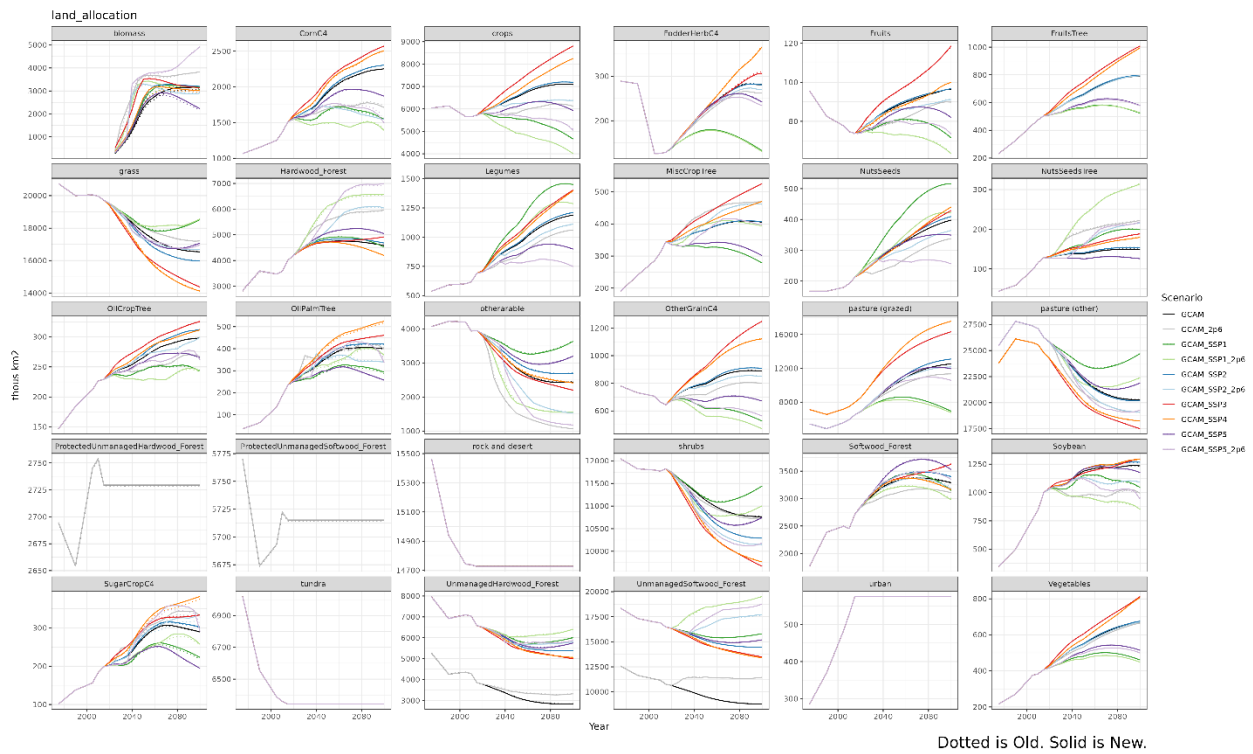


Figure 11: Land allocation globally

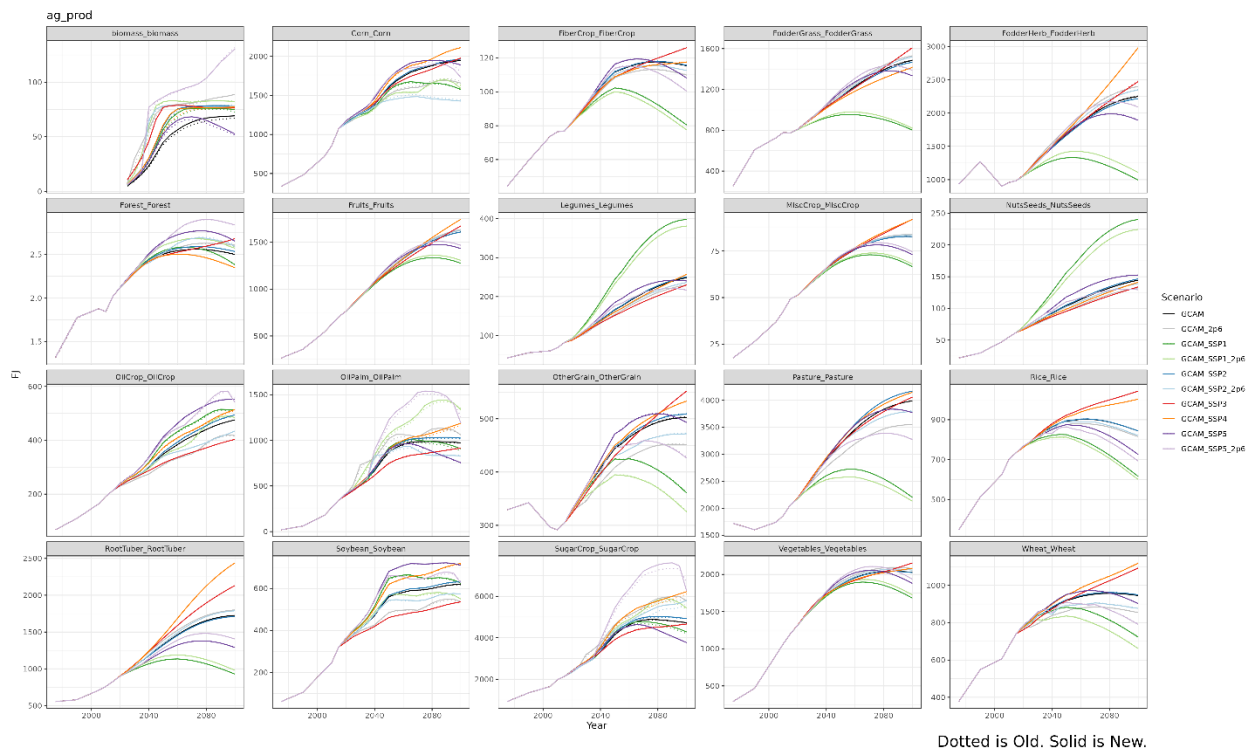


Figure 12: Agriculture production by crop globally

Documentation Updates

GCAM's documentation is being updated to include Ukraine in default GCAM regional definitions and modify instances of total GCAM regions mentioning 32 regions to an arbitrary number of regions.

Additional Figures

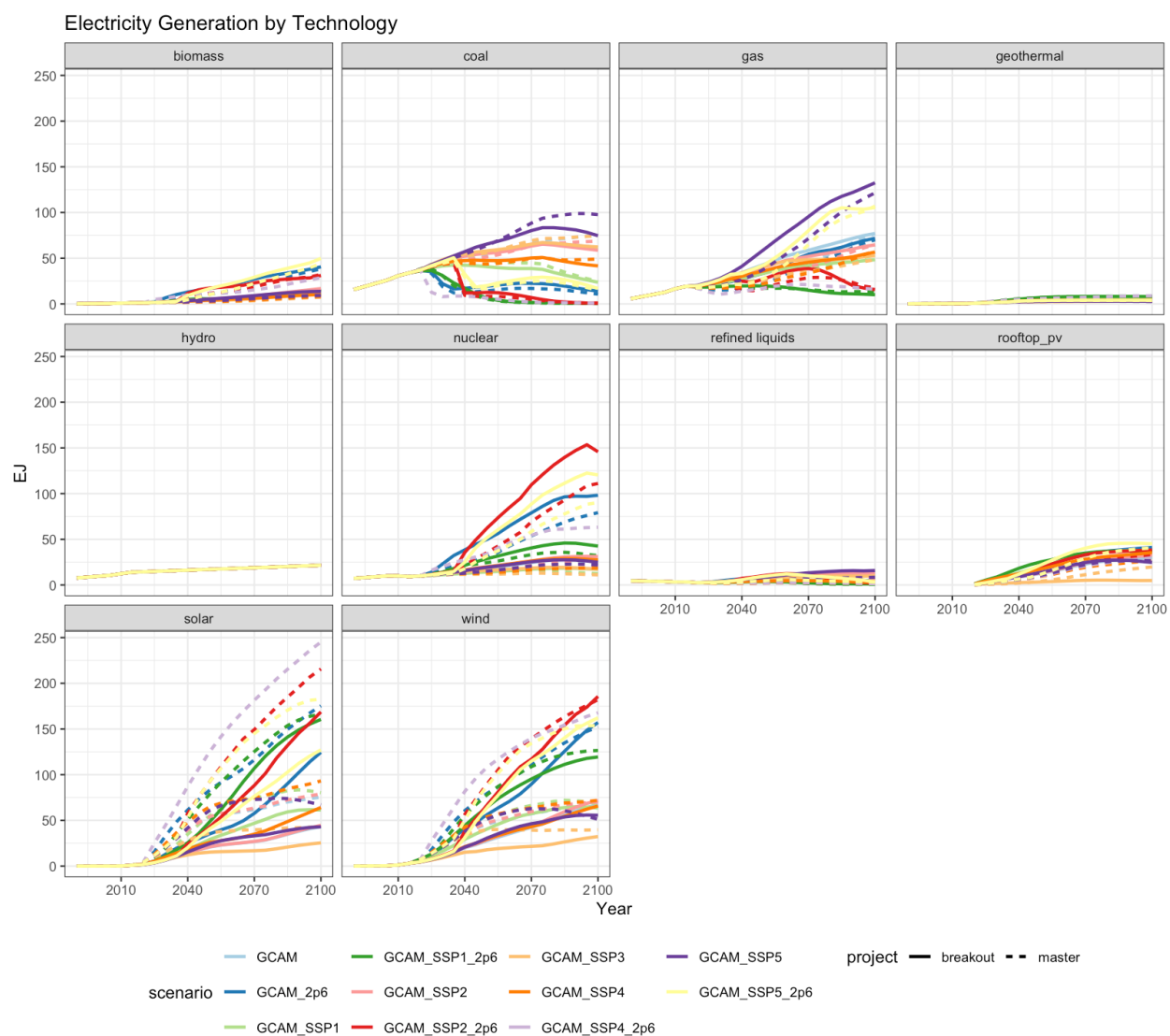


Figure 13: Electricity by Generation Technology Aggregated

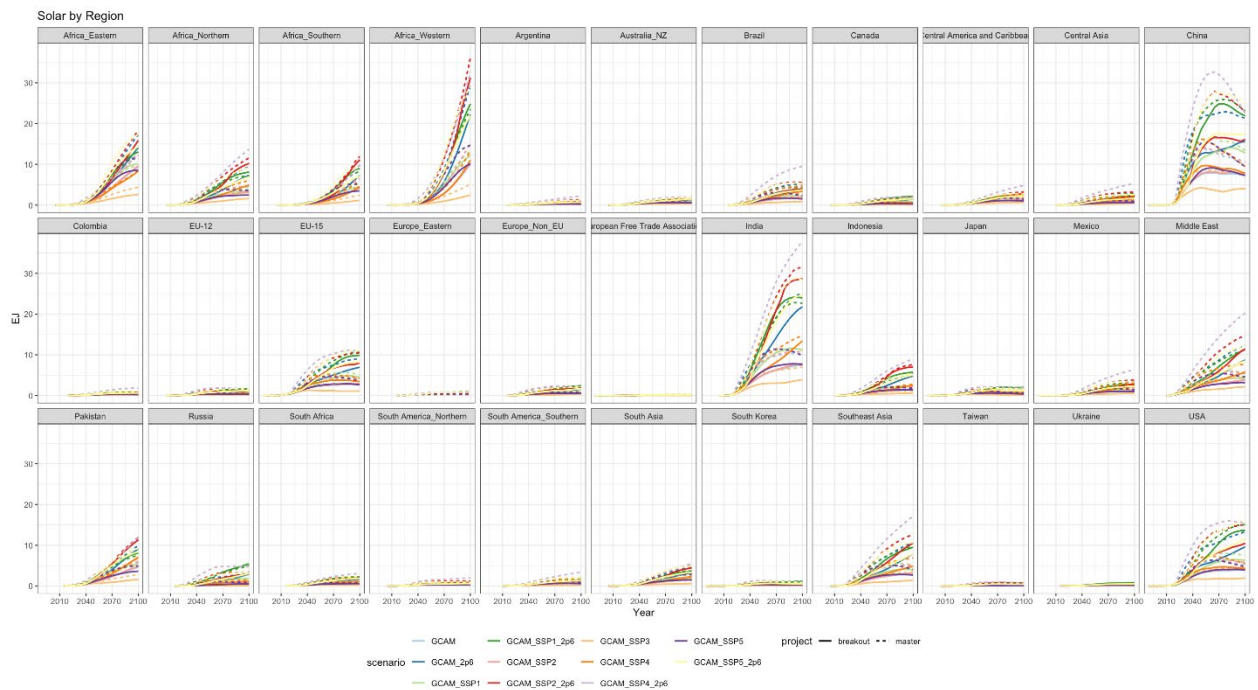


Figure 14: Solar Electricity Generation by Region

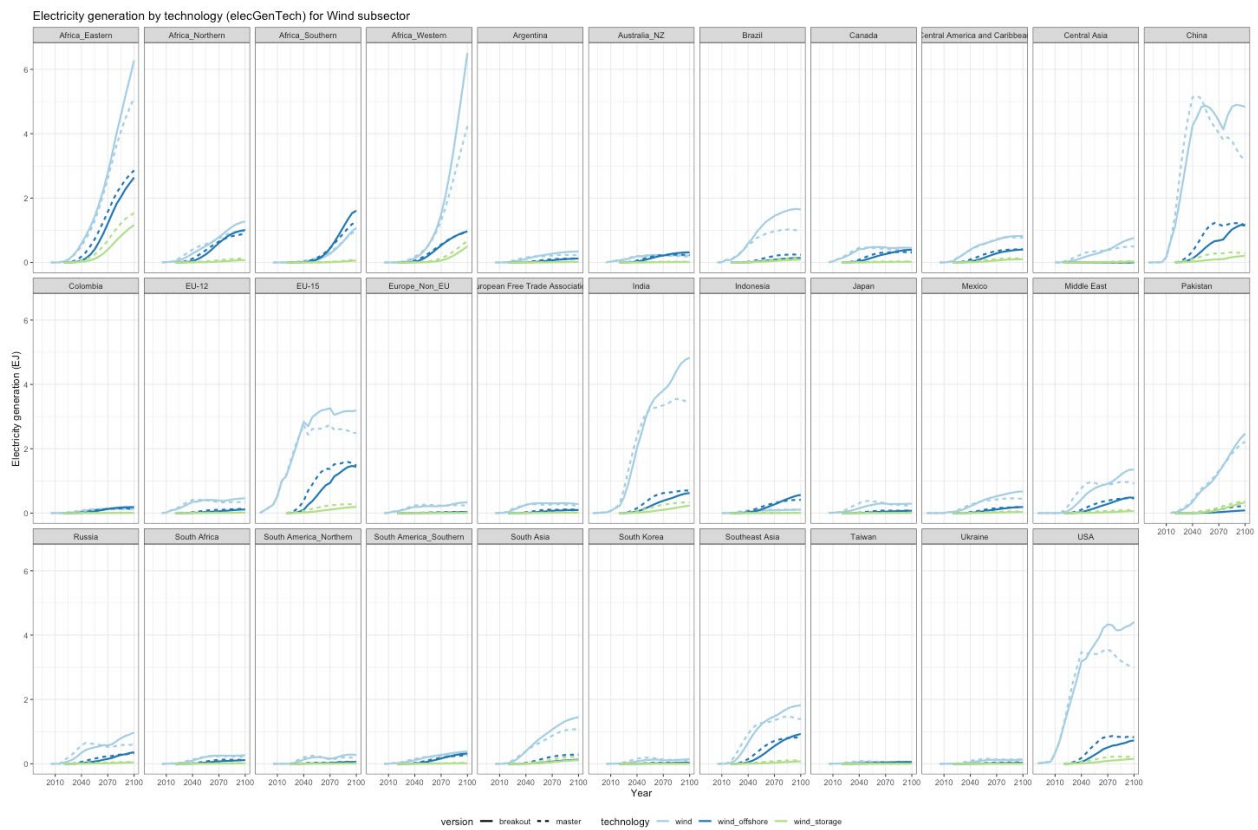


Figure 15: Wind Electricity Generation by Region

Pacific Northwest National Laboratory

902 Battelle Boulevard
P.O. Box 999
Richland, WA 99354

1-888-375-PNNL (7665)

www.pnnl.gov