Core Model Proposal #367: GCAM v6.0 transportation bugfix

Product: Global Change Analysis Model (GCAM)

Institution: Joint Global Change Research Institute (JGCRI)

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Date committed: 14 Feb 2023

IR document number: PNNL-34180

Related sector: energy

Type of development: code, data

Purpose: This Core Model Proposal corrects several bugs in the GCAM v6.0 transportation sector: (1) an abrupt shift in freight road output by mode from 2015 to 2020 related to the (newly-introduced) profit shutdown decider, (2) a decline in passenger service output for four-wheel light-duty vehicles between 2015 and 2020 for many regions, and (3) over-optimistic efficiencies for electric airplanes.

Description of Changes

Shift in freight road output by mode from 2015 to 2020 related to the profit shutdown decider

In GCAM v6.0, we observed an abrupt shift in freight road output by mode from 2015 to 2020 (Table 1). Total road transport service output increases marginally (~8%) from 2015 to 2020, which is expected. However, heavy truck output decreases by more than 10% while light truck and medium truck service output increases by more than 50% and 33%, respectively.

This can be traced back to technology output by vintage (Table 2). Within each freight size class, the 2015 vintage has lower production in 2020 than in 2015; this is a result of both natural retirements and profit shutdown retirements. The profit shutdown feature is new as of pull request 262. However, the output of the heavy truck 2015 vintage falls dramatically (nearly 90%), while the 2015 vintage for other modes experience much smaller output reductions.

The technology / mode investment shares are relatively stable from 2015 to 2020, suggesting that the shift in total model level service output is attributable to reduction in output of the 2015 vintage, not changing investment patterns for the 2020 vintage (Table 3.

Table 1: Transportation Service Output by Mode

scenario	**region**	**sector**	**mode**	**2015**	**2020**	**Units**
Reference	USA	trn_freight	Domestic Ship	1,045,950	1,086,972	million ton-km
Reference	USA	trn_freight	Freight Rail	2,163,940	2,312,340	million ton-km
Reference	USA	trn_freight	road	1,699,890	1,832,050	million ton-km
Reference	USA	trn_freight_road	Heavy truck	1,043,010	927,441	million ton-km
Reference	USA	trn_freight_road	Light truck	66,186.5	102,408.5	million ton-km
Reference	USA	trn_freight_road	Medium truck	590,699	802,197.2	million ton-km

Table 2: Transportation Service Output by Tech and Vintage

scenario	**region**	**sector**	**subsector**	**tech**	**vintage**	**2015**	**2020**	**Units**
Reference	USA	trn_freight_road	Heavy truck	Liquids	2015	1,043,010	120,668	million ton-km
Reference	USA	trn_freight_road	Light truck	Liquids	2015	66,186.5	47,877.2	million ton-km
Reference	USA	trn_freight_road	Medium truck	Liquids	2015	590,699	349,947	million ton-km

Table 3: Transport Service Output by Tech (new)

scenario	region	sector	subsector	tech	2015	2015 (share)	2020	2020 (share)	Units
Reference	USA	trn_freight_road	Heavy truck	Hybrid Liquids		0%	28,861	2%	million ton-km
Reference	USA	trn_freight_road	Heavy truck	Liquids	1,043,010	61%	777,912	59%	million ton-km
Reference	USA	trn_freight_road	Light truck	Hybrid Liquids		0%	7,036	1%	million ton-km
Reference	USA	trn_freight_road	Light truck	Liquids	66,187	4%	47,496	4%	million ton-km
Reference	USA	trn_freight_road	Medium truck	Hybrid Liquids		0%	25,378	2%	million ton-km
Reference	USA	trn_freight_road	Medium truck	Liquids	590,699	35%	426,872	32%	million ton-km

Two changes were made in response to this issue:

- In zchunk_batch_transportation_UCD_CORE_xml.R, remove the L254.GlobalTranTechProfitShutdown table so that the profit shutdown decider is not printed to the XMLs for all transportation technologies. The input file containing transportation technology profit shutdown decider parameters, as well as the associated data processing, are left in place so that users have the option to set up a profit shutdown decider for transportation technologies if desired.
- In tran_technology.cpp, several changes were made to adjust technology costs by load factor to ensure that technology costs and sector prices are always in the same units. Prior to this CMP, the profit shutdown decider would compare technology costs in $/vehicle-mi to a sector price in $/pass-mi or $/ton-mi. This contributed to the issue freight retirements because heavy trucks have high costs per vehicle but also high load factors; thus, comparing heavy truck costs in $/vehicle-mi to a $/ton-mi sector price led freight trucks to appear very uneconomical for the profit shutdown decider equation.

Decline in passenger service output for four-wheel light-duty vehicles between 2015 and 2020 for many regions

In GCAM v6.0, we observed that passenger service output declines for four-wheel light-duty vehicles (LDV 4W) between 2015 and 2020 for many regions. The reason for this is, as of pull request 197, GCAM's Bus technologies are vintaged but compete against a technology without a lifetime (LDV). While light-duty passenger vehicles are vintaged at the technology level in the sectors corresponding to vehicle chassis (trn_pass_road_LDV_4W, trn_pass_road_LDV_3W, trn_pass_road_LDV_2W), the trn_pass_road_LDV sector represents the cumulative output of these technologies and is itself not vintaged. Having a vintaged technology compete against a non-vintaged technology typically leads to the former gaining share over time, because it's stock accumulates while the latter's does not.

To resolve this issue, bus technology lifetimes have been removed from energy/A54.globaltranTech_retire.csv and energy/A54.globaltranTech_retire_revised.csv.

Over-optimistic efficiencies for electric airplanes

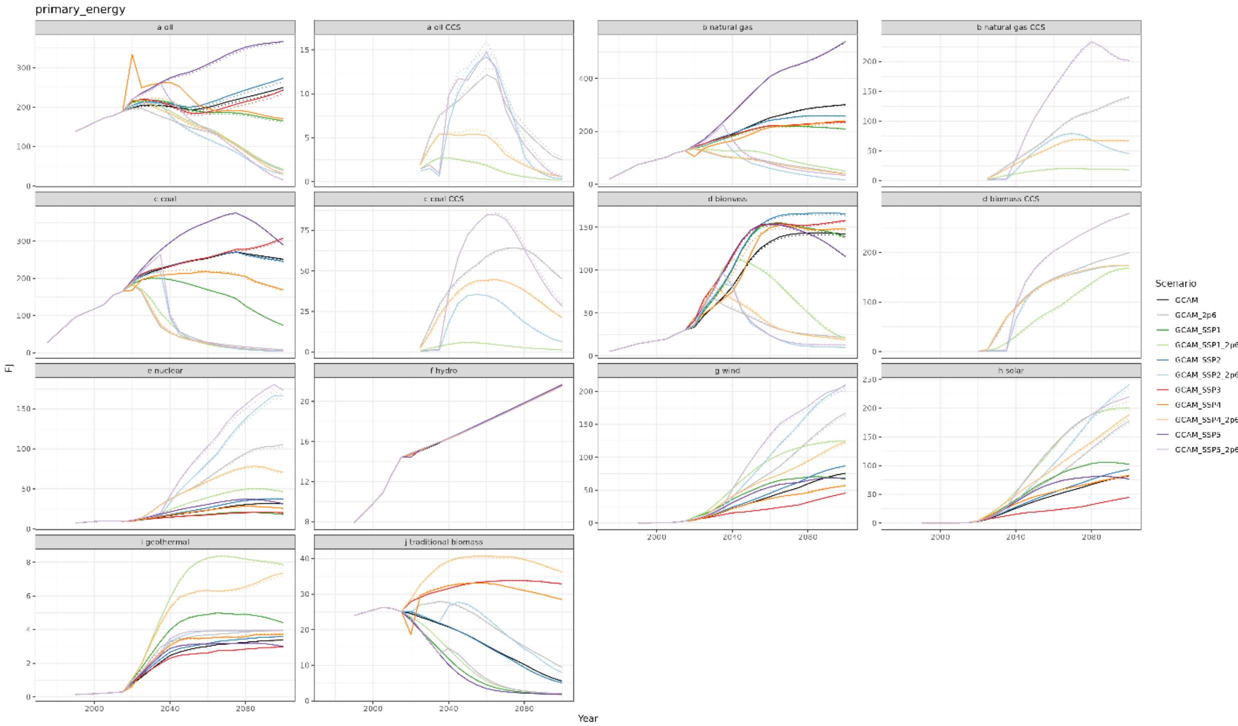
Presently, BEV airplanes are assigned higher efficiencies than standard jet airplanes because electric motors have higher efficiency than jet engines. However, the Schafer et al. 2019 paper (which was used to define GCAM's BEV airplane technology) specifies that the total energy intensity of a BEV airplane ends up being the same as a standard jet, because the additional weight of the batteries offsets the efficiency advantage of the electric motor. This proposal updates the efficiency assumptions for BEV airplanes in energy/OTAQ_trn_data_EMF37.csv.

Validation

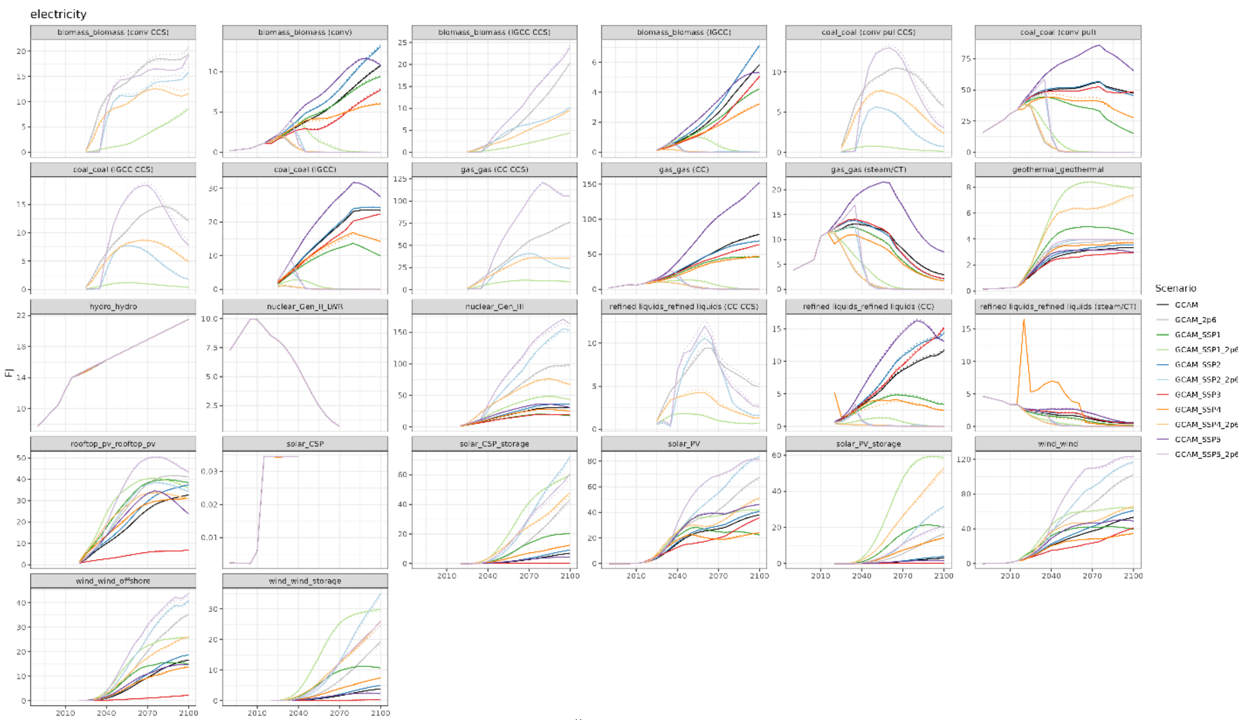
The standard set of GCAM validation scenarios were run; selected results are presented below. Note that the GCAM-USA_Tax scenario was not available for the current main branch, so comparison results aren't available for that scenario. For all sections besides "Overall results", two figure types are shown. One figure type is stacked bar charts - these charts have scenarios arrayed in the rows, the current "main" GCAM branch in the first (leftmost) column, the results from this proposal in the second column, and (in most cases) the difference ("diff"; proposal - main) in the third column. The other figure type is line plots, with different panels for each scenario and the model branch (main vs. proposal) distinguished by linetype. All figures shown are global in scope unless otherwise noted.

Overall results

The anomaly detector results for GCAM's standard validation runs show only minor impacts (at a global level) for key energy system variables, such as primary energy and electricity (below). The full set of anomaly detector figures are included here (detector.zip). Note that SSP4 filed periods 2020, 2030, and 2035, and SSP5 failed period 2020, so larger anomalies may show up for those scenarios / periods.



Dotted is Old. Solid is New.



Dotted is Old. Solid is New.

High-level transportation results

Figures 1-5 show high-level transportation service and final energy results. Overall, changes to freight transportation service (Figure 1), freight transportation final energy (Figure 4), and total transportation final energy (Figure 4) are small at the global level. Passenger transportation service (Figure 2) increases noticably in all scenarios; in 2100, passenger transportation service increases between 3.5% (SSP5_2p6) and 7.0% (SSP3) as a result of this proposal, relative to main. The corresponds to an even larger increase in passenger final energy (Figure 5), which ranged between 8.8% (SSP5) and 20.6% (SSP5_2p6) higher in 2100 in this proposal, relative to main. The additional passenger transportation service demand, this increase in energy use is attributable to: (1) reduced reliance on busses (an efficient transportation mode) in place of LDVs (a less efficient mode) and (2) lower aggregate aviation efficiency as a result of the lower BEV plan efficiencies in this proposal.

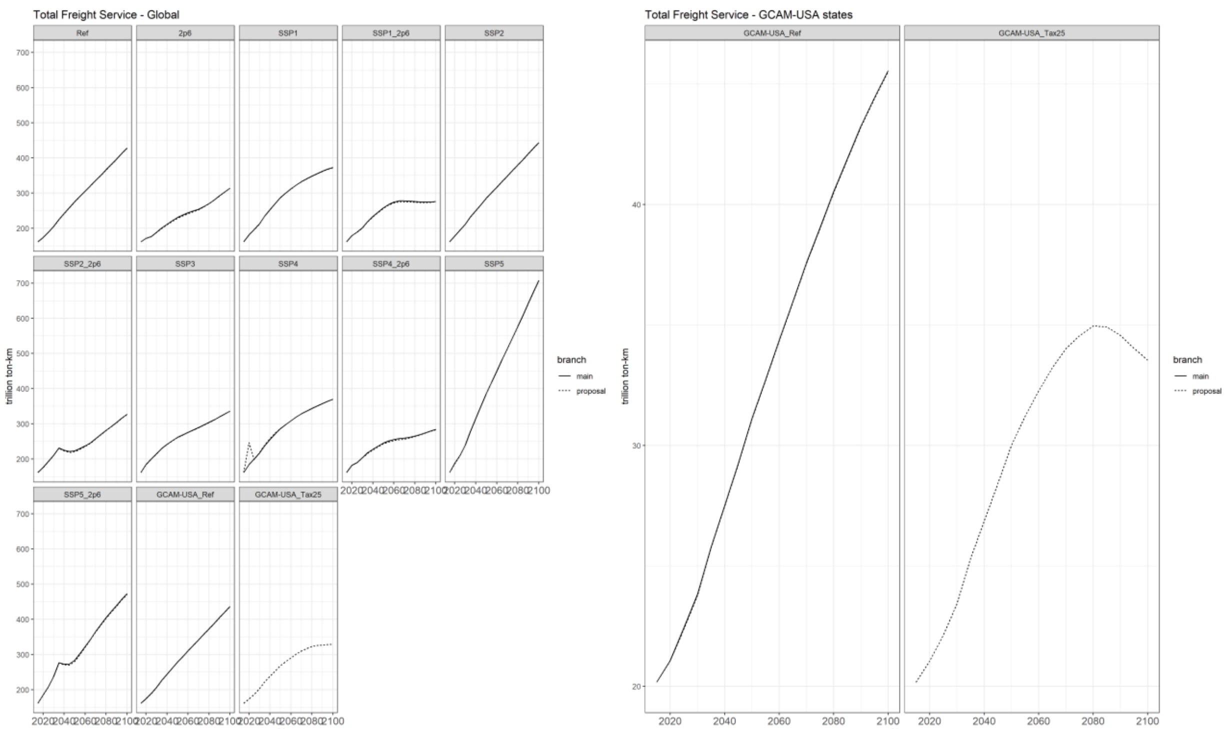


Figure 1 - Freight transportation service

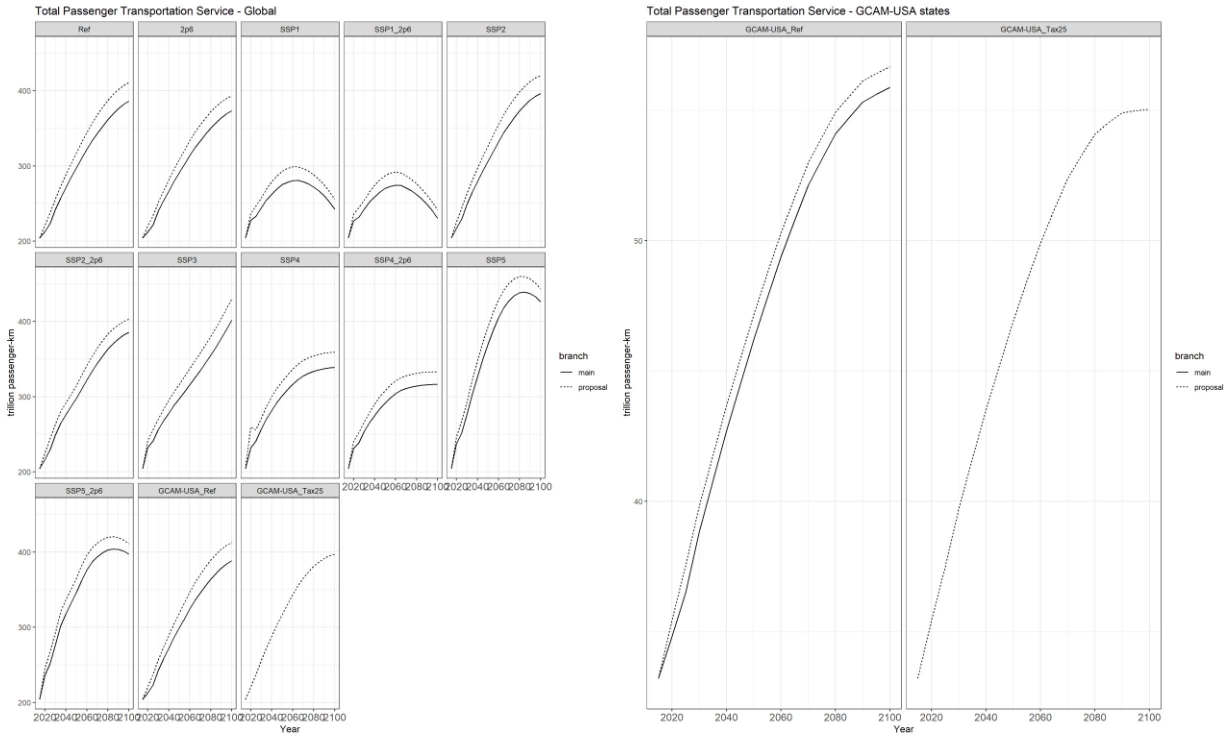


Figure 2 - Passenger transportation service

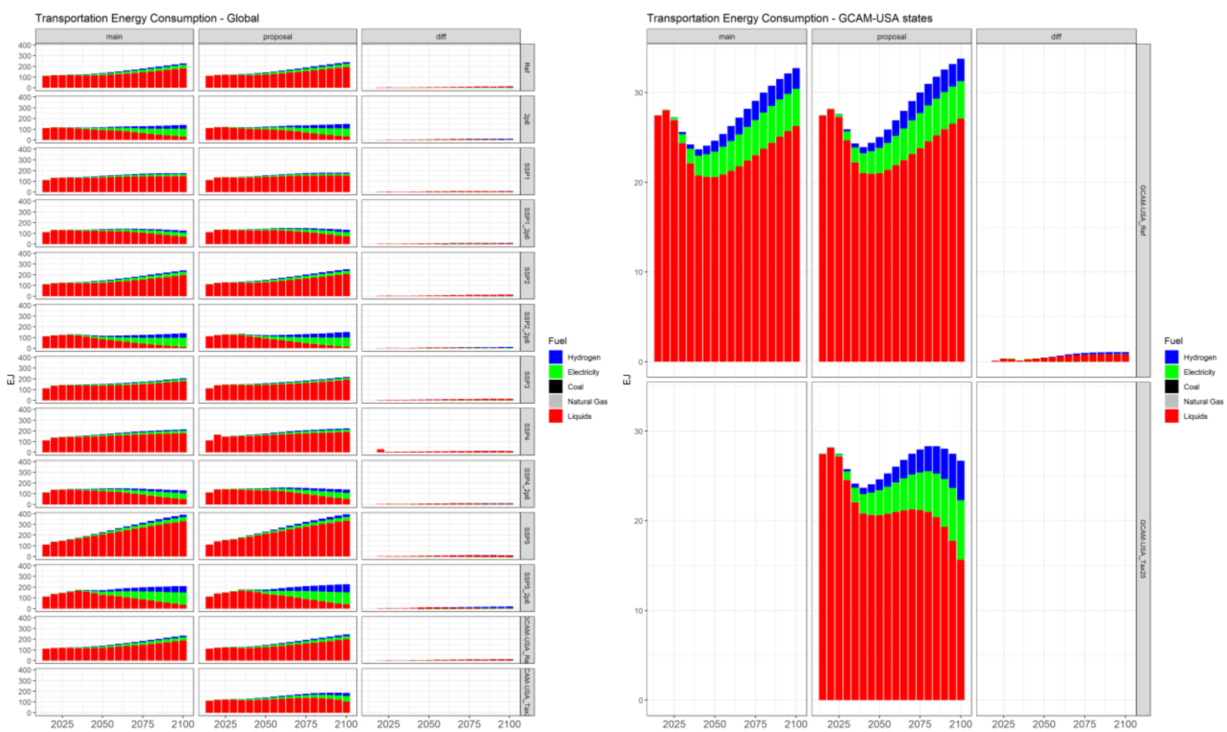


Figure 3 - Total transportation final energy by fuel

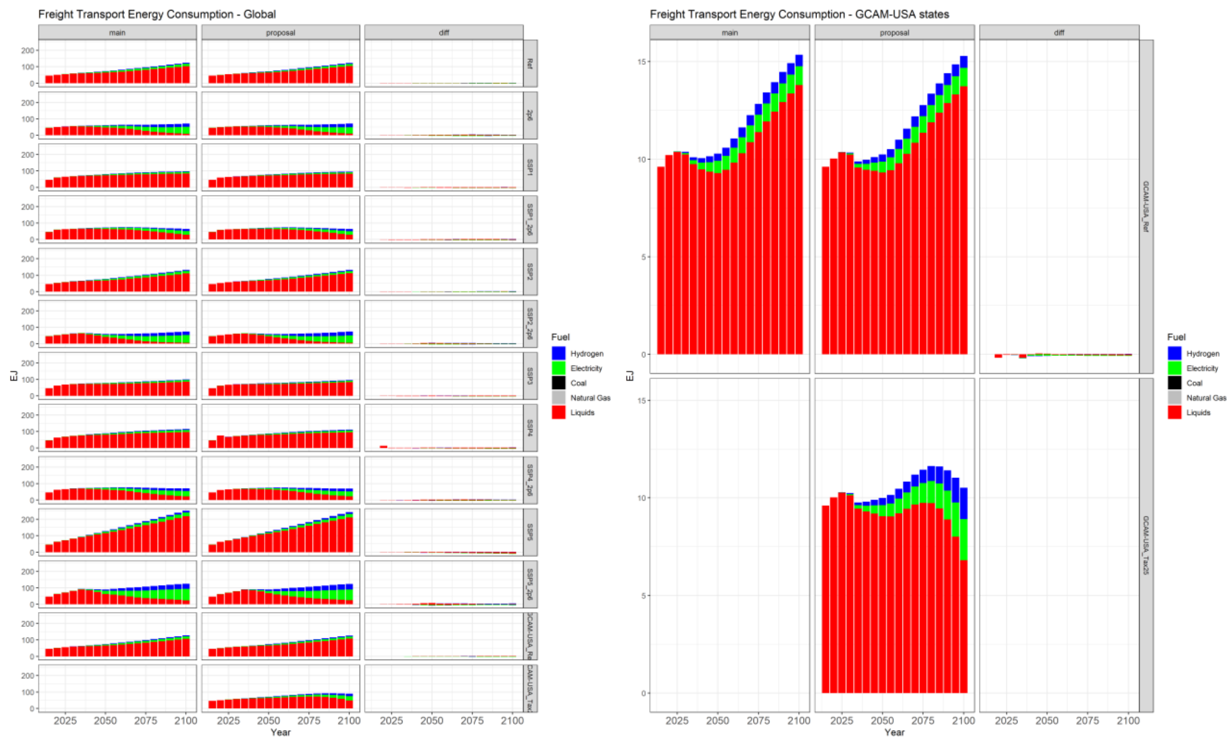


Figure 4 - Freight transport final energy by fuel

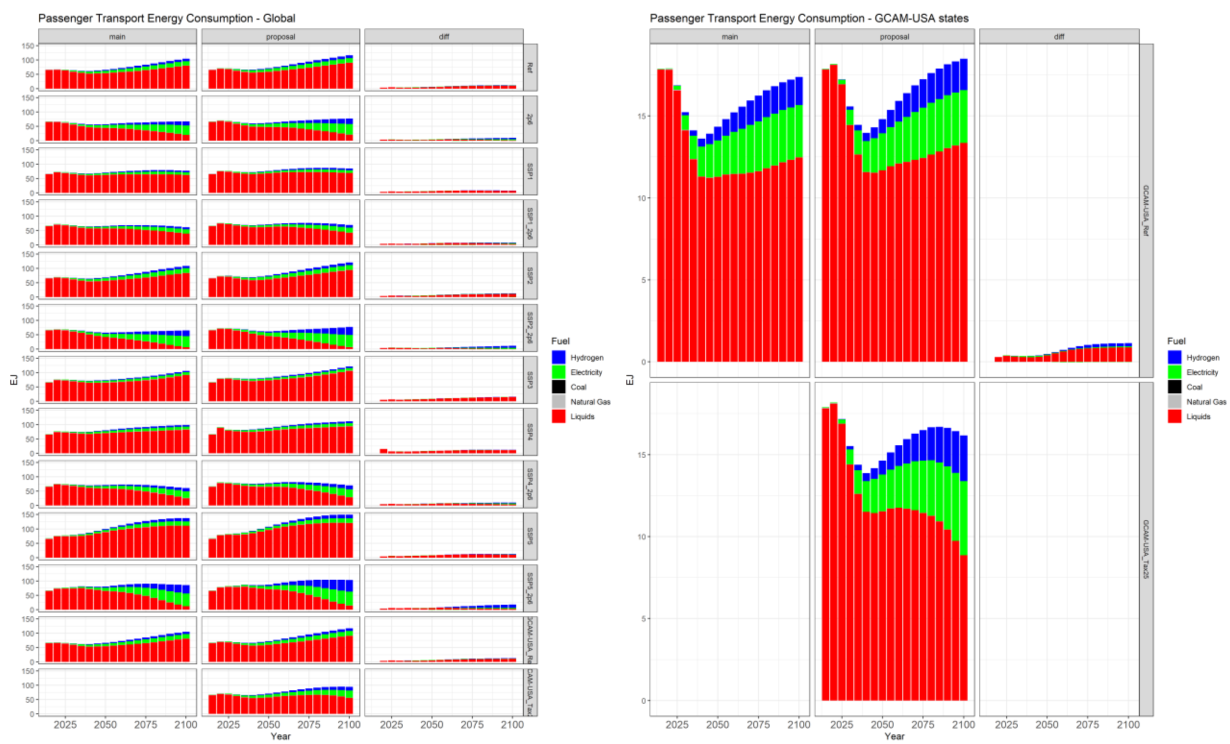


Figure 5 - Passenger transportation final energy by fuel

Freight transport - truck

Figures 6 & 7 present freight truck service output. Figure 6 shows freight truck service output for the 2015 technology vintage. This shows the rapid shutdown of freight trucks, especially heavy trucks, in the main branch (left panels) and demonstrates that this proposal corrects the issue (right panels). Figure 7 shows total freight truck service output; the impact of this proposal is relatively minor in terms of total freight truck service output at the global level, although the difference plot confirms that results change in the expected direction (more heavy trucks and less light/medium trucks as a result of removing the removing the profit shutdown decider and the associated C++ bug fixes, which previously caused disproportionate retirement of heavy trucks).

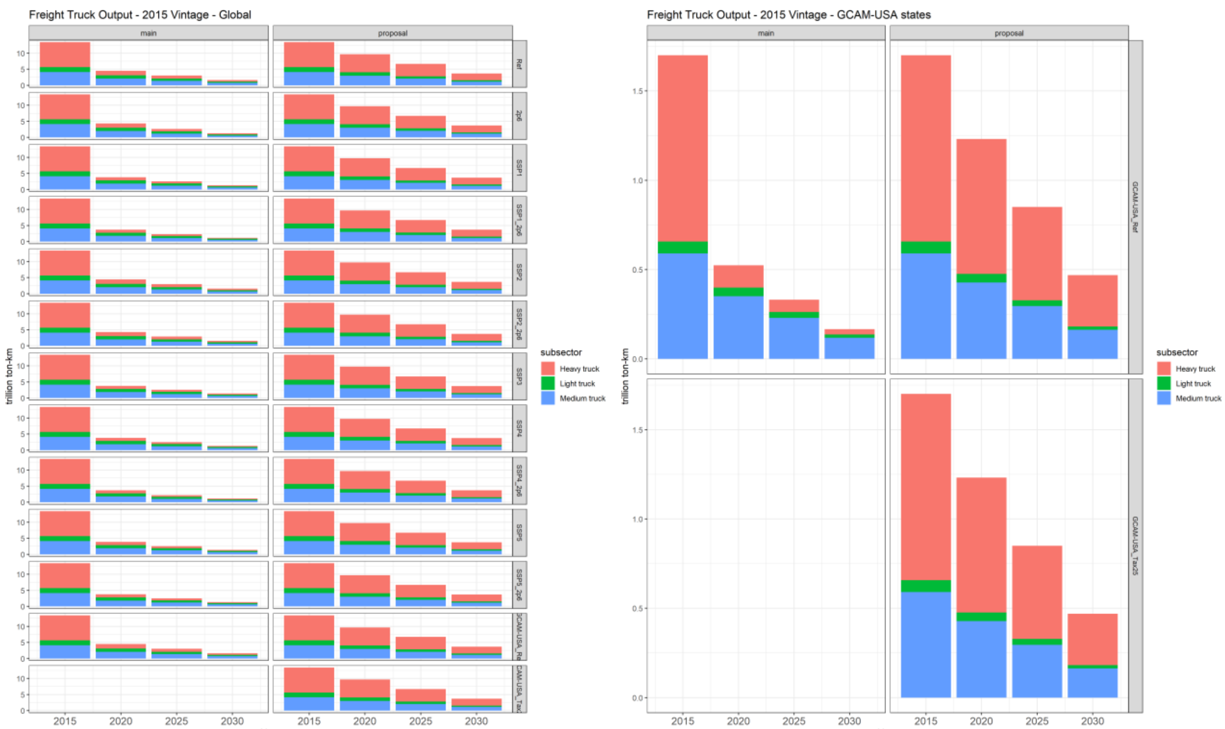


Figure 6 - Freight truck service output by size class - 2015 technology vintage

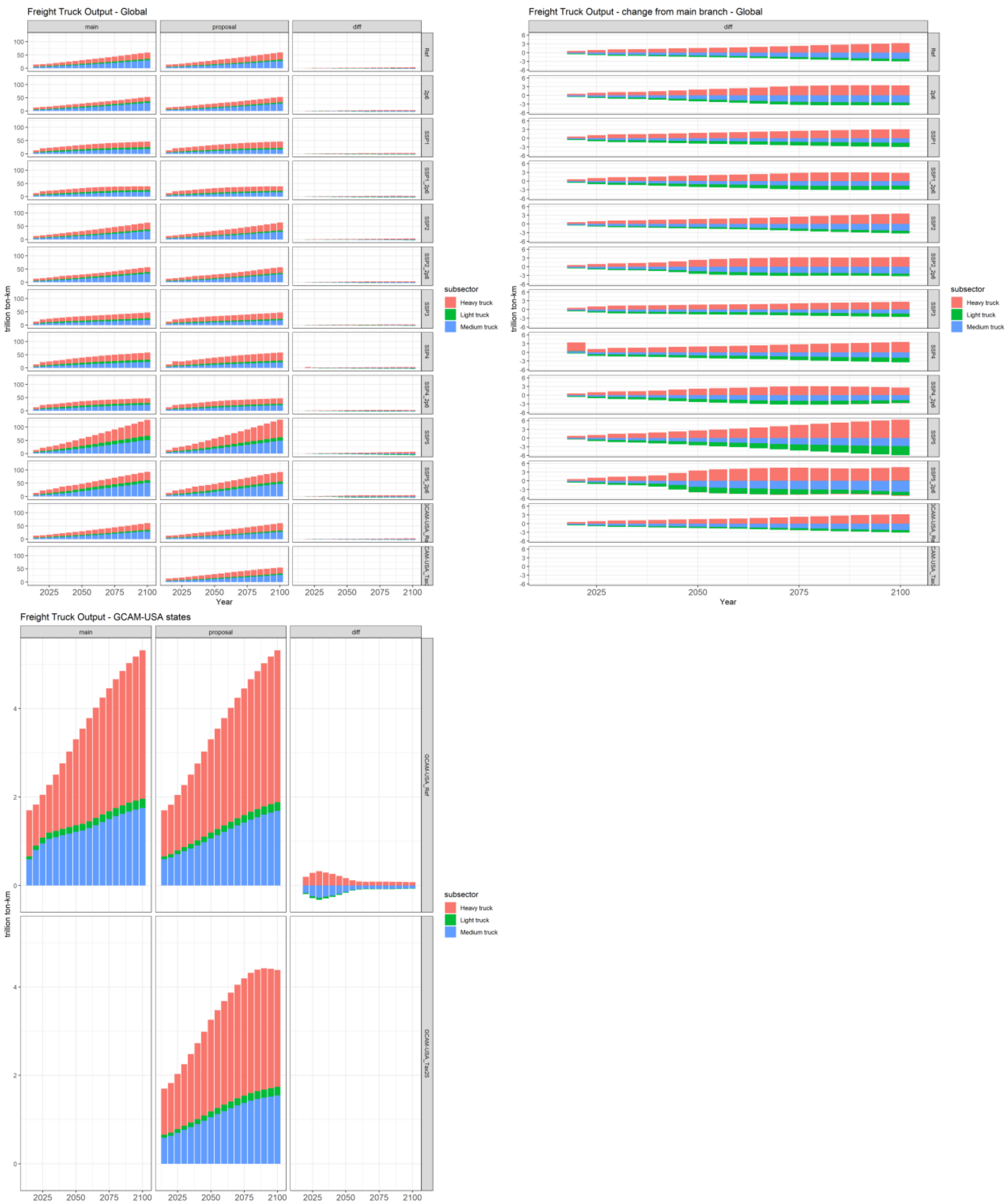


Figure 7 - Freight truck service output by size class (center figure is focused difference plot)

Passenger transport - bus vs. LDV

Figure 8 shows the division of road-based passenger transportation service between personal vehicles and busses. Overall, the removal of vintaging for the bus technologies leads to relatively minor changes in results, with slightly lower passenger transport provided by busses and slightly more provided by LDV as a result of this proposal (relative to main). Figure 9 shows that the removal of lifetimes (vintaging) for busses worked as expected; while previously the 2015 vintage for busses continued to operate in 2020 and 2025 (left column), this proposal (right column) shows that neither bus or LDV technologies in the "trn_pass_road" sector operate for more than one model period.

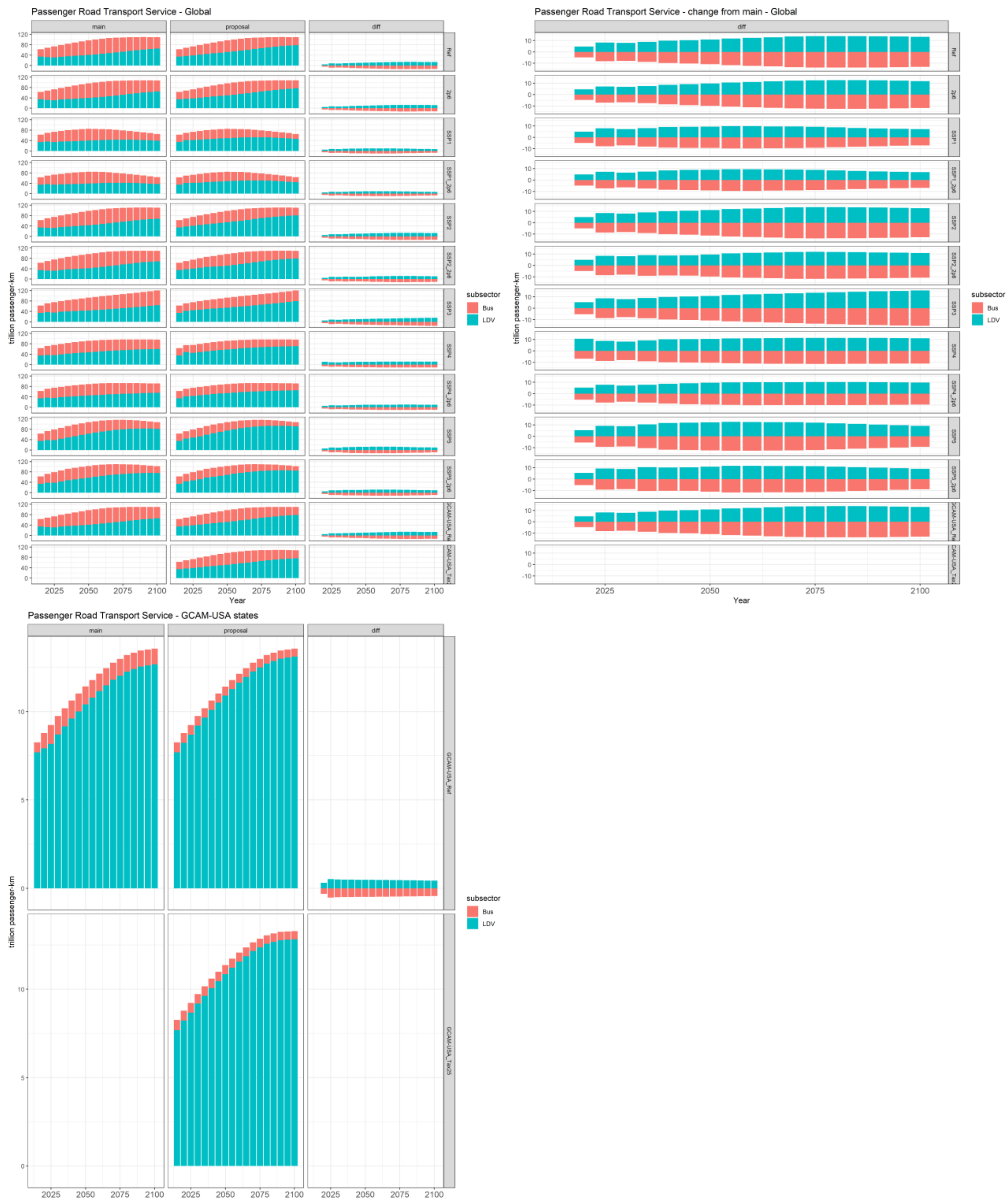


Figure 8 - Passenger road service output (bus vs. light-duty vehicle (LDV))

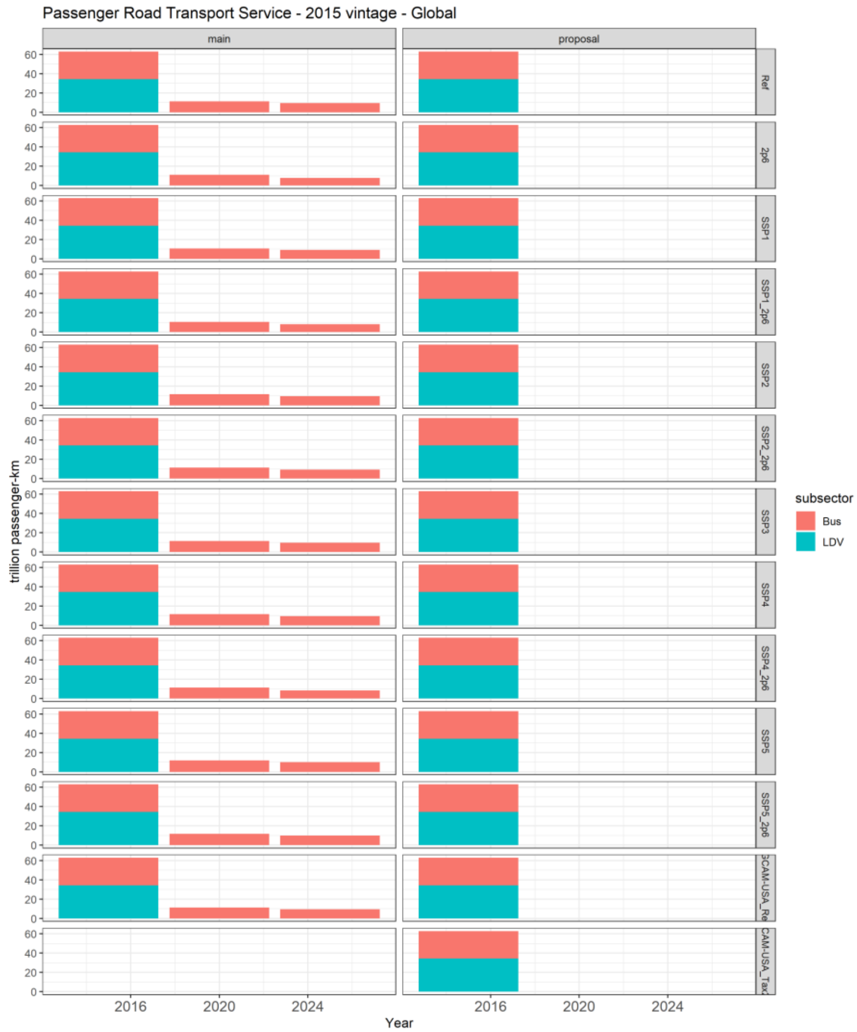


Figure 9 - Passenger road service output for 2015 vintage (bus vs. light-duty vehicle (LDV))

Airplanes

Figures 10-12 show aviation service output by technology. Figure 9 shows domestic aviation; Figure 10 shows international aviation; Figure 8 shows total aviation service (domestic + international). Note that electric airplanes have range restrictions which limit their deployment for international aviation; thus, international aviation results are largely unimpacted by this proposal (which changes BEV plane efficiencies). In terms of domestic aviation (and by association, total aviation), the BEV plan efficiency updates in this proposal lead to lwoer BEV plane deployment across all scenarios. BEV planes are displaced mostly by traditional jets (liquid fueled planes) in cases without a climate policy target; in cases which target 2.6 W/m2 of radiative forcing at the end of the century (2p6 case), BEV planes are mostly displaced by hydrogen planes in this propsal (relative to main).

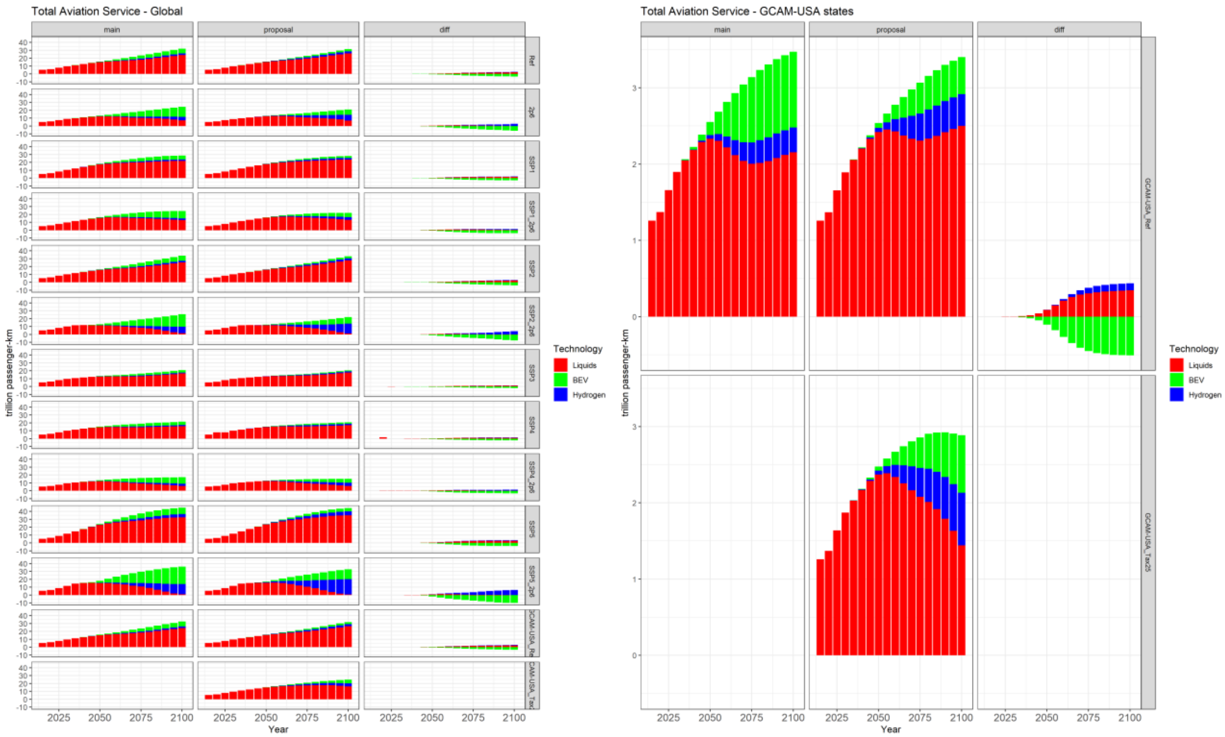


Figure 10 - Total aviation service output by technology

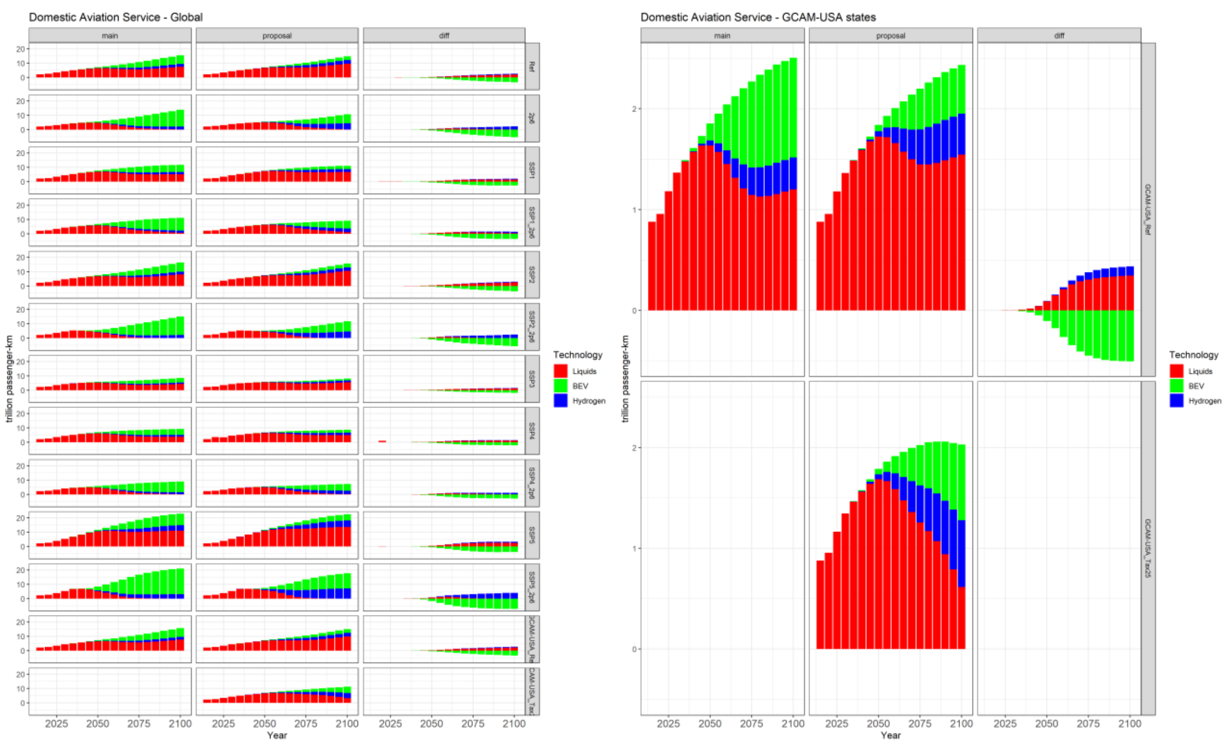


Figure 11 - Domestic aviation service output by technology

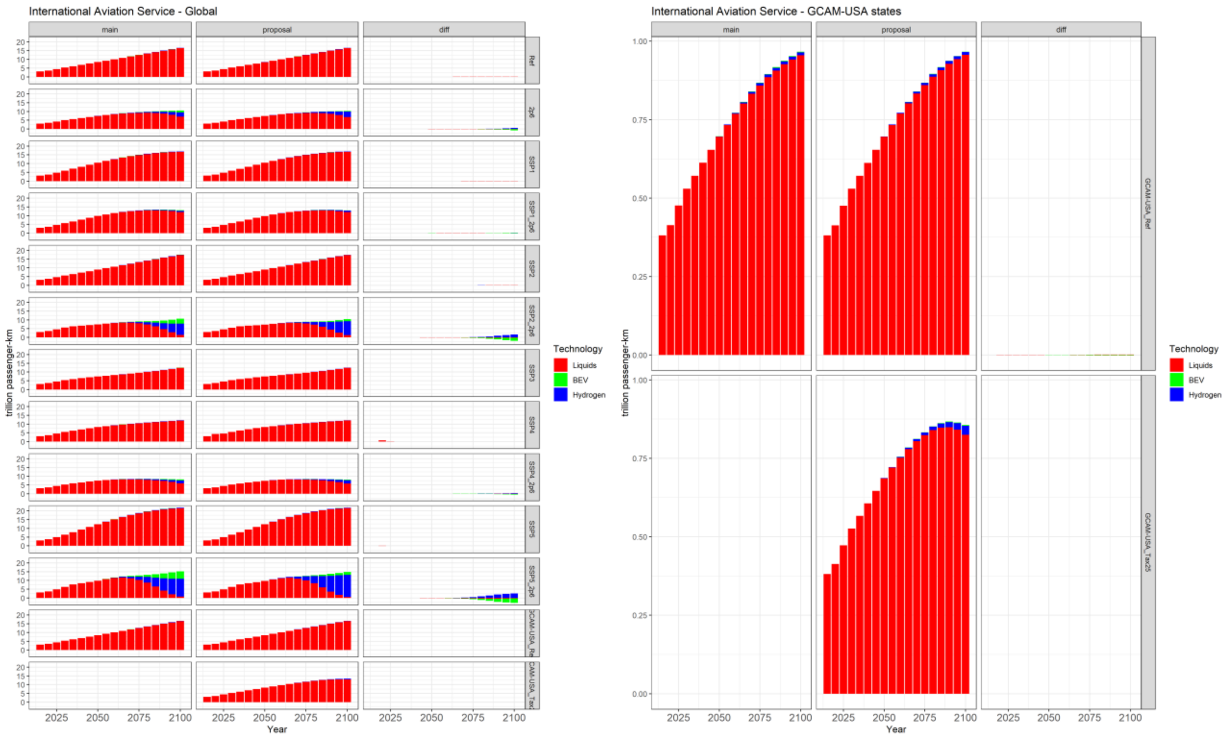


Figure 12 - International aviation service output by technology

Citations

Schäfer, A.W., Barrett, S.R.H., Doyme, K. *et al.* Technological, economic and environmental prospects of all-electric aircraft. *Nat Energy* **4**, 160–166 (2019). https://doi.org/10.1038/s41560-018-0294-x