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GCAMUSAJobs: An R package for employment projections based on GCAM-USA power sector outcomes

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Summary

The GCAMUSAJobs R package was developed to post-process electric power projections from GCAM-USA, enabling the estimation of future power sector jobs at the state-level by generation technology and job type. GCAMUSAJobs extends GCAM-USA functionality by estimating the capacity levels of different activities – operational capacity, capacity addition, and retirement; and calculating jobs associated with those activities, including operation and maintenance (O&M), construction, and decommissioning. Additionally, this package is designed to be easily adaptable to the output of other energy system models and Integrated Assessment Models (IAMs) besides GCAM-USA.

Statement of need

It is important to assess the distributional labor impacts of energy system evolution, which can affect labor demand across regions, technologies, and skill groups (Hanson, 2023; Mayfield et al., 2023; Raimi, 2021; Xie et al., 2023). While gross employment (Mayfield et al., 2023) and power sector employment (Xie et al., 2023) are expected to grow into the future under both business as usual (BAU) and alternative scenarios, these aggregate trends mask important distributional differences. Xie et al. (2023) find insignificant differences in the United States (U.S.) national power sector jobs between BAU and decarbonization scenarios; however, distributional differences across U.S. states are much more significant. For example, fossil fuel-intensive states may experience slower job growth or job losses, which was also found in other studies (Hanson, 2023; Mayfield et al., 2023).

The Global Change Analysis Model (GCAM) and its regional extension GCAM-USA with state-level details (JGCRI, 2025) are integrated multi-sector models that focus on the interaction among human activities, technology, and physical systems. They are powerful tools for studying energy systems dynamics and evolution. Many previous studies have applied the model to analyze potential impacts on the energy system and associated outcomes due to environmental and socioeconomic changes (e.g., Feijoo et al., 2020; Ganji et al., 2024; Ou et al., 2018; Pan & Shittu, 2025; Zhang et al., 2025). Currently, GCAM-USA does not calculate power sector jobs. GCAMUSAJobs addresses this gap by providing projected direct power sector jobs based on GCAM-USA output, enhancing the functionality of GCAM-USA for labor impact analysis.

State of the field

Existing studies extended IAMs to include employment impacts through post-processing IAM outputs combined with employment factors (Emmerling et al., 2025; Malik et al., 2021; e.g., Pai et al., 2021). However, these studies estimated the employment impacts at EU-country level or broader regional level. To our knowledge, there is currently no tool that extends the capability of an integrated multi-sector model or IAM at subnational level, such as GCAM-USA, to analyze the impact of energy system changes on employment. The most closely related available tool is the Jobs & Economic Development Impacts (JEDI) model (NLR, 2025). JEDI develops employment factors (jobs per unit of capacity) for a range of power generation technologies. In contrast, `GCAMUSAJobs` uses JEDI results as an input, combining them with outputs from GCAM-USA to analyze employment consequences of alternative energy system futures. `GCAMUSAJobs` is complementary to JEDI, filling a methodological and software gap by bridging the capability of GCAM-USA (or other energy system models) with the information provided by JEDI, without duplicating or modifying either of the models.

Software design

The direct purpose of `GCAMUSAJobs` is to calculate the number of different types of jobs in the power sector (e.g., O&M workers, construction workers, decommissioning workers) across U.S. states, built upon the existing open-source model GCAM-USA. As GCAM-USA is a complex multi-sector model with technological details, our design involves in-depth understanding and testing of how various components work together in GCAM-USA, especially in the power sector, so that we can properly design the jobs calculation in our package and source available matching data (e.g., employment factors). This requires irreplaceable human efforts to comprehend the existing software and extend its capability through collaboration with GCAM-USA modelers and domain experts in socioeconomics.

`GCAMUSAJobs` is designed to be easily adaptable to the output of broader energy system models to enable extended employment analysis. `GCAMUSAJobs`'s workflow moves from annual electricity generation outputs, to estimation of underlying capacity levels based on assumptions about capacity factors, to calculations of associated power sector jobs based on employment factors (Figure 1). For GCAM-USA users, the workflow is simplified by directly ingesting GCAM-USA output databases in their original format and automatically performing capacity activity and employment analysis. For users of other energy system models or IAMs, `GCAMUSAJobs` provides detailed employment factors extracted from simulations of the JEDI model, which calculates employment factors under a range of assumptions about power sector technologies. This means users can supply capacity activity output from an energy system model or IAM in the required format and conduct employment analysis using those readily applicable employment factors. The employment factor represents the average number of jobs created per unit of power production activity (e.g., jobs per gigawatt). This method is widely used in the relevant literature (Mayfield et al., 2023; Rutovitz et al., 2015). `GCAMUSAJobs` adopts employment factors from the JEDI model, which has been broadly used in the literature (Jacobson et al., 2017; Rutovitz et al., 2015; Xie et al., 2023).

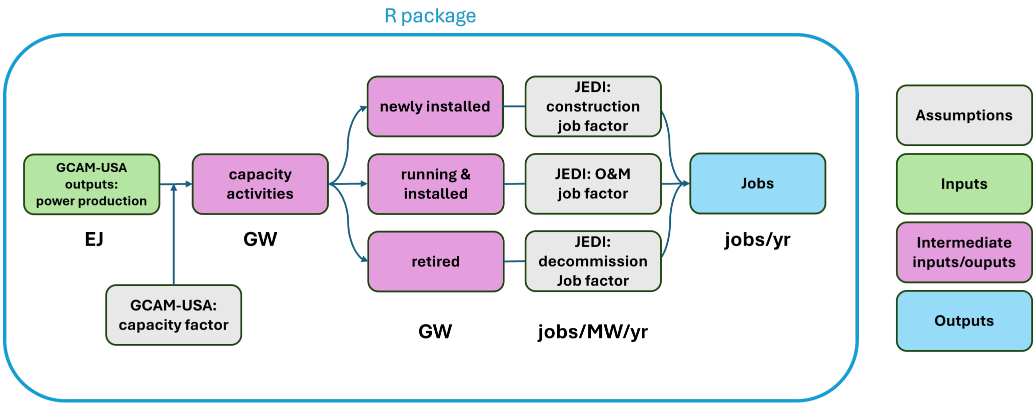

Figure 1: Package workflow.

The package structure also allows users to access intermediate outputs and develop custom functions to examine or adapt analytical components. Besides, `GCAMUSAJobs` includes user-configurable options for key model assumptions and built-in visualization tools for rapid diagnostics. The following section provides a brief description of key functions of this package. A detailed methodology is available at https://jgcri.github.io/GCAMUSAJobs/articles/methods.html

Key functions

`GCAMUSAJobs::GCAM_EJ` queries power generation data (in exajoules, EJ) from the GCAM-USA output database for a single scenario, disaggregating generation from existing plants, newly added plants, and the generation lost from recently retired plants. The output is provided annually, broken down by state and fuel technology. Building on this, `GCAMUSAJobs::GCAM_GW`, taking the output from `GCAMUSAJobs::GCAM_EJ`, calculates the average annual capacity levels (in gigawatts, GW) by state and fuel technology for different activities, including operation, addition, and retirement. It supports both the "Total" and "Net" methods. In the "Total" method, all capacity additions and retirements are counted separately. In the "Net" method, premature retirement is offset with capacity addition. The "Total" method is better suited for large states with many facilities, where it is plausible that while one plant is retiring, a facility at a different location in the state is beginning construction. In small states with few facilities, simultaneous retirement and addition may not reflect reality. For example, if only one coal plant exists in a small state and it retires, any new capacity is likely a direct replacement, not a separate project. In this case, the replacement would imply a lower number of jobs needed than if the retirement and addition occurred as separate projects. The two options of user-defined methods ensure that job estimates for capacity expansion and decommissioning remain realistic and regionally appropriate. `GCAMUSAJobs::GCAM_JOB` then utilizes the output from `GCAMUSAJobs::GCAM_GW` to estimate the average annual job estimates, broken down by fuel type and job type, including construction (both on-site and construction-related), operations & maintenance, and decommissioning. Users can select between the "Total" or "Net" method, with "Total" used as the default. `GCAMUSAJobs` also provides a list of functions to visualize the employment factor assumptions, capacity, and job outcomes.

`GCAMUSAJobs::GCAM_EJ` is compatible with both the GCAM-USA output database as well as a project data file queried using the R package `rgcam`. Please refer to the package vignette for additional examples and visualizations.

Research impact statement

GCAMUSAJobs enables a new workflow to analyze various potential impacts on power sector jobs across U.S. states. Sources of impact include, but are not limited to, socioeconomic development, environmental change, policy targets, and technological advancement. GCAMUSAJobs can perform ex-ante quantitative analysis of the associated distributional impacts on state-level power sector jobs. It can support analytical work in academic research and inform policymaking by providing useful information for preparedness and targeted responses to the anticipated impacts. For demonstration purposes, we use GCAMUSAJobs to post-process the outcome from GCAM-USA v7.1 for a standard reference scenario, estimating the direct job, aggregated over states, associated with U.S. power generation (Figure 2).

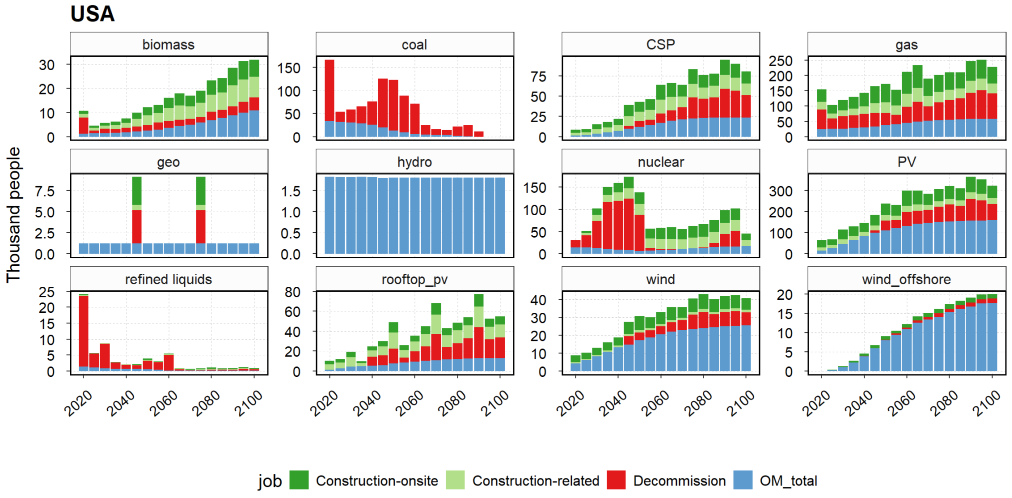

Figure 2: Annual average power sector jobs by fuel and job types over a 5-year model period. Note that y-axes have different scales.

GCAMUSAJobs has been used by researchers at the University of Maryland (external adopter) for a published report on the renewable energy transition in Maryland and its implications (Kennedy et al., 2024). Specifically, the report provides direct job estimates at Maryland's thermal power plants based on facility characteristics (e.g., nameplate capacity, capacity factor, and fuel type) and the employment factors produced by this package. Additionally, GCAMUSAJobs is being used in an ongoing PhD dissertation at the University of Maryland. Meanwhile, the package is expected to be developed by external researchers to expand its capabilities and grow its user base.

AI usage disclosure

No generative AI tools were used in the development of this software, the writing of this manuscript, or the preparation of supporting materials.

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