Reconciling Economic Structures with Future Scenarios: A Stepwise Optimization Framework for Robust Prospective MRIO Construction

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Multi-regional inputâ€“output (MRIO) models provide an accounting framework for quantifying environmental impacts along global supply chains, enabling the identification of environmental burdens and supply-chain risks associated with production and consumption. However, as standard MRIO databases provide only static snapshots of historical economic structures, they cannot address the "forward-looking" analysis of climate policy and sustainability transitions in the long term. To project environmental risks under different socioeconomic futures, researchers typically integrate exogenous data from dynamic models such as Integrated Assessment Models (IAMs) into historical MRIO tables.

While IAMs provide detailed pathways for energy, crops, land use, and emissions, they often lack the full cross-sectoral economic granularity of a MRIO. Consequently, most studies incorporate only a limited subset of scenario variables, typically updating energy-related intermediate coefficients while leaving the broader economic structure to be projected via a standard Leontief inverse. This "hybrid" approach prioritizes structural fidelity in MRIO but risks substantial inconsistency with the underlying IAM scenario. Absolute IMAGE data such as GDP, sectoral outputs, or energy inputs, which are direct or indirect determinants of the resulting energy structure, are frequently ignored to avoid the "structural distortion" in MRIO that may occur when two fundamentally different modeling frameworks are reconciled.

This study systematically examines the trade-off between scenario compliance and structural fidelity. We investigate how sensitive prospective MRIO tables are to the progressively expanded enforcement of scenario data and identify where the most significant coefficient adjustments emerge as more scenario constraints are imposed.

We employ a two-stage workflow combining Leontief-based projection with optimization-based reconciliation. Using EXIOBASE (2019) as a historical baseline and IMAGE scenario outputs (2035, SSP2) as the prospective reference, we first incorporate available future energy and crop coefficients and structures derived from IMAGE into the coefficient matrices, and project a MRIO using the updated Leontief inverse and a scaled final demand. This step preserves historical inputâ€“output relationships to infer economic components that are not explicitly specified in the IMAGE scenario, consistent with common practice in prospective MRIO studies.

Due to the baseline data difference (EXIOBASE versus IMAGE in historical years), modelling difference (Leontief inverse versus IMAGE modelling), and hidden scenario assumptions behind IMAGE which are not integrated in the Leontief based projection, there are heterogeneous gaps in macroeconomic indicators, sector outputs, and transaction flows between Leontief-based projected outcome and IMAGE. To bridge the gaps, we develop an optimization framework, which enforces IMAGE constraints sequentially, while minimizing structural distortion (defined as deviations in MRIO coefficients). This allows the generation of a series of prospective tables representing increasing levels of "scenario intensity," including:
â€¢ Macro-economic indicators (GDP, Value Added).
â€¢ Sectoral outputs for heavy industries and transport.
â€¢ Energy production and consumption.
â€¢ Crop production and consumption.

By analyzing the trajectories of key coefficients, transaction flows, and Global Warming Potential (GWP), we assess the sensitivity of economic structure and environmental footprints to these alternative integration designs.

This research provides three primary contributions to the field. First, it reveals the extent of modeling uncertainty inherent in prospective MRIO construction, demonstrating how environmental footprint outcomes fluctuate depending on the level of IAM enforcement. Second, the proposed sequential optimization approach makes the trade-off between scenario alignment and structural fidelity measurable. This allows researchers to choose an integration strategy that is mathematically transparent. Third, it introduces a diagnostic measure based on coefficient deviations which helps to identify where IAM scenario constraints conflict most sharply with established MRIO structures, highlighting areas where technical coefficients in MRIO must undergo radical (and perhaps unrealistic) shifts to meet climate targets in IAM.

Ultimately, these findings improve the transparency of scenario-based footprint analysis. By identifying the uncertainties introduced during the harmonization of IAM and MRIO data, this study provides a roadmap for more robust and consistent forward-looking environmental assessments.