# OpenSEFA: An Open Web Platform for Substance and Energy Flow Analysis

Data reconciliation for material, substance and energy flow systems

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*Material Flow Analysis (MFA) and Substance and Energy Flow Analysis (SEFA) aim to quantify the material and energy flows and stocks of a system based on field and inventory data, which are often sparse, uncertain, and mutually inconsistent, and which may violate conservation of mass and energy.* ***OpenSEFA*** *is a browser-based application for visual SEFA modeling in the Substance & Energy Flow Modeling Notation (SEFMN) and addresses these data limitations. It supports nonlinear data reconciliation to adjust measured values, and uncertainty propagation to calculate the uncertainties of unknown quantities computed from these reconciled values. Both methods are subject to automatically generated balance constraints to achieve* ***physical consistency****. Optional* ***aggregation layers*** *support follow-on accounting such as $CO_2$ emissions. A free hosted instance is at opensefa.matplus.eu; the reconciliation engine* ***OpenSEFA.jl*** *is on GitHub under the PolyForm Noncommercial License 1.0.0.*

## 1. Introduction

MFA and SEFA map material and energy flows through a defined system – for example a production plant, a municipality, or a national economy. They support process analysis and optimization, help identify resource-saving and efficiency potentials, and provide a basis for further calculations such as $CO_2$ accounting (Brunner & Rechberger, 2016).

Core model elements include **processes** (transformation steps) that are characterized by **transfer coefficients** partitioning their inputs to outputs, **flows** (material or energy transfers), and **stocks** (accumulated quantities). SEFA extends MFA to coordinated mass, energy, and substance layers, allowing them to be tracked separately through the system.

In practice, field and inventory data are often sparse, uncertain, and not physically consistent – they violate conservation of mass and energy when combined. Even though credible follow-on accounting, including $CO_2$, needs reconciled flows, established practice stops short of unifying reconciliation with built-in aggregation for such derived quantities. OpenSEFA closes this gap. It provides similar functionality to **STAN**, where graphical MFA modeling, nonlinear data reconciliation, and uncertainty propagation were established (Cencic, 2016), but offers the following additional features: it unifies reconciliation with optional follow-on accounting via aggregation layers (with $CO_2$ accounting already implemented), uses a solver that is designed for faster solutions on large systems and that respects variable bounds, and offers a web-native platform with an openly available solver and structured JSON model exchange.

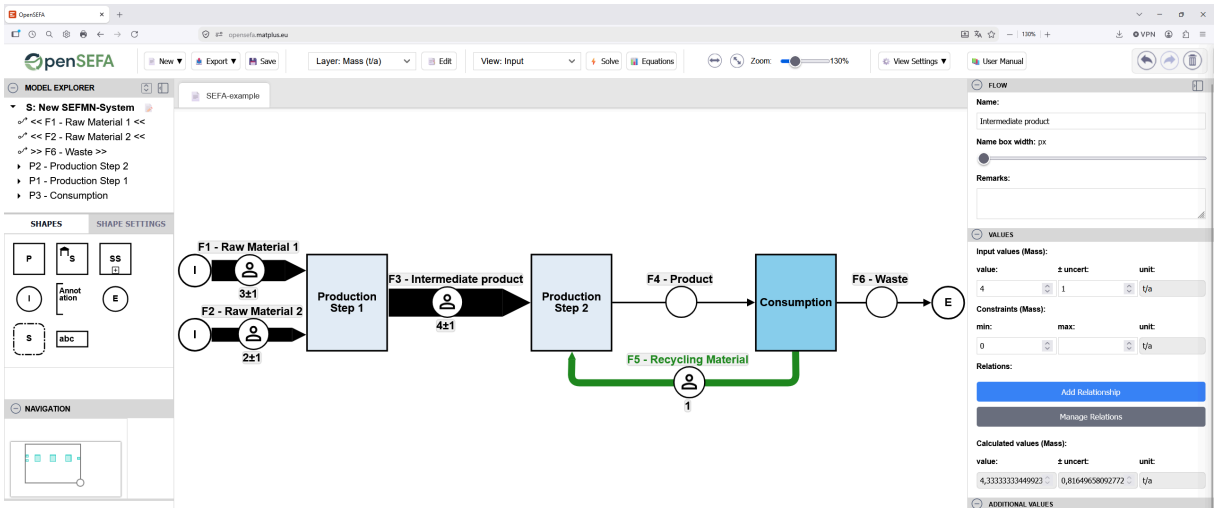



*Figure 1: OpenSEFA with prototypical SEFA system (user input before solving). Measured flows F1–F3 carry uncertainties; F5 is fixed; F4 and F6 are unmeasured.*

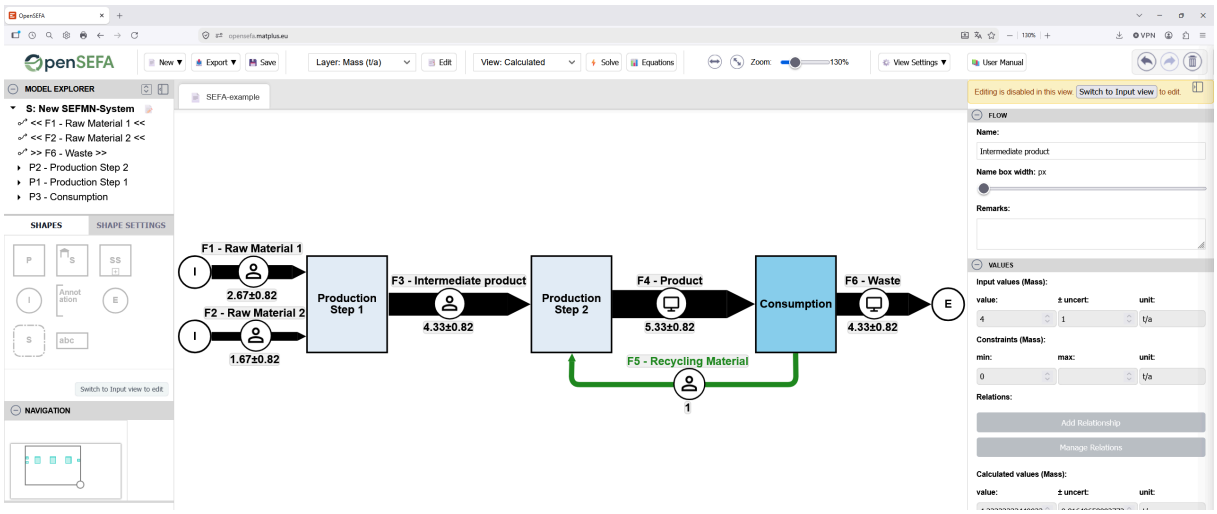



*Figure 2: Same system after reconciliation (calculated view). Measured values are adjusted and missing flows F4 and F6 are computed so that conservation of mass holds.*

## 2. Data Reconciliation

Data reconciliation aims at physical consistency through **conservation of mass and energy**: for each process, inputs equal outputs plus net stock change. As systems grow, the equation structure becomes too large to balance by hand. When transfer coefficients are reconciled jointly with flows, process balances introduce **bilinear constraint terms** – products of decision variables – alongside linear conservation equations. OpenSEFA takes over this work following the formulation of MFA reconciliation by Cencic (2016) as a **nonlinear optimization problem** under such constraints, with measured variables and their uncertainties in the objective.

**Measured variables** $x$ represent quantities whose true values are unknown; for each, the user supplies a measurement $x_m$ and its standard uncertainty, assuming normally distributed measurement errors. Reconciliation estimates the most probable values of $x$ from the measurements, their uncertainties, and the balance constraints. **Unmeasured variables** $y$ are estimated from constraints, without direct measurements. **Fixed variables** $z$ are known

without uncertainty. With $Q$ the diagonal matrix of squared uncertainties, the optimizer minimizes weighted deviation from measurements:

$$\min_{x,y}(x - x_m)^T Q^{-1}(x - x_m)$$

subject to balance constraints, for $i = 1, \ldots, k$:

$$f_i(x, y, z) := c_i + a_i^T \begin{bmatrix} x \\ y \\ z \end{bmatrix} + \begin{bmatrix} x \\ y \\ z \end{bmatrix}^T B_i \begin{bmatrix} x \\ y \\ z \end{bmatrix} = 0$$

Each constraint combines a constant term $c_i$, linear coefficients $a_i$, and optionally bilinear terms via $B_i$. Variable bounds apply componentwise to $x$ and $y$. A presolve stage simplifies the system – substituting fixed values, resolving trivial and bilinear assignments, and removing redundant equations – before numerical optimization. Reconciliation uses a **local nonlinear optimizer**: for nonconvex problems (with bilinear constraints), convergence can depend on initial values; thus, global optimality is not guaranteed. After reconciliation, uncertainties are propagated through the model structure under the normal-error assumption (Cencic, 2016).

## 3. The OpenSEFA Platform

OpenSEFA combines a visual SEFA editor with a reconciliation solver in one browser application. A running instance is available at opensefa.matplus.eu.

Users build models by placing processes, stocks, and subsystems on the canvas and connecting them with flows. They enter measured values with uncertainties and bounds, define transfer coefficients for processes and optional linear flow relationships. After solving, reconciled results return to the interface for analysis and export. For guidance, an integrated user manual is available.

Behind the interface, the OpenSEFA solver (OpenSEFA.jl) uses refined algorithms for faster, more stable solutions on large systems and respects variable bounds during reconciliation. The optimization problem is formulated once in **JuMP**, which allows different numerical solvers to be used without rewriting the model. When a model is solved, balance equations from the diagram are sent to this engine automatically.

OpenSEFA covers the workflow from model building to export:

- **Visual SEFMN modeling** – processes, stocks, subsystems connected by flows
- **Data input** including transfer coefficients, uncertainties, bounds, and linear relationships
- **Multi-layer analysis** – mass, energy, and substance layers in one model
- **Aggregation layers** for $CO_2$ emissions, costs, and derived quantities
- **Integrated solving** with inspection of equations, solve results, and infeasibility diagnostics
- **User manual** for MFA/SEFA concepts, workspace use, and layer configuration
- **Export** of JSON models and diagram images for documentation and reporting

## 4. Availability, Licensing, and Community

A free hosted web application at opensefa.matplus.eu combines the visual SEFA editor with the reconciliation solver. The solver is also openly available as OpenSEFA.jl on GitHub under the PolyForm Noncommercial License 1.0.0. Matplus welcomes feedback, ideas, and suggestions from users to guide further development.

As an active research prototype, OpenSEFA continues to evolve based on community use.

| Resource | Access |
|---|---|
| **Web application** (incl. user manual) | opensefa.matplus.eu – free browser application; email registration required |
| **Solver (OpenSEFA.jl)** | GitHub – source and documentation; PolyForm Noncommercial 1.0.0 |
| **Editor source** | Available from Matplus on request; valid JointJS+ license required |

Commercial deployment or integration may require separate arrangements with Matplus; component licenses differ.

## References

Brunner, P. H., & Rechberger, H. (2016). *Handbook of Material Flow Analysis: For Environmental, Resource, and Waste Engineers.* CRC Press.

Cencic, O. (2016). Nonlinear data reconciliation in material flow analysis with software STAN. *Sustainable Environment Research*, 26(6), 291–298.

STAN 2.7 (release 2.7.101, 2022). Software by the Research Unit of Waste and Resource Management, TU Wien, and inka software. www.stan2web.net/