

ENERGY TECHNOLOGY SYSTEMS ANALYSIS PROGRAM (ETSAP)

TIMES / VEDA METADATA FRAMEWORK

**Expanding TIMES model files with metadata for improved
communication of input data and results**

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Summary

VEDA (the VEDA2.0 interface for TIMES) now includes a structured metadata system that embeds documentation directly into Excel model input files. Modelers can attach standardized metadata—such as source, author, version, date, and comments—to technologies, commodities, and data values at different scopes (workbook, worksheet, row, column, or table). VEDA reads and displays this metadata consistently during the full modeling workflow.

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This system addresses frequent issues in TIMES modeling, including missing data provenance, limited version control, inconsistent documentation practices, and difficulties collaborating across multiple users. By linking contextual information directly to model inputs, it becomes easier to understand the origin, purpose, and evolution of data entries, strengthening transparency, quality assurance, and model governance.

Metadata is defined through configurable dimensions in the *~md_dimensions* table and applied using tags of the form *~md-<element>_<scope>*. Metadata entries use a simple “dimension: value” syntax and may be spread across adjacent cells. A clear hierarchy determines which metadata takes precedence across scopes, while comments from different levels are combined.

A proof-of-concept was implemented using the TIMES Demo model. It demonstrates how metadata tags can be applied in practice and how VEDA interprets and displays them. This framework provides a foundation for more transparent, documented, and maintainable TIMES models across the ETSAP community.

1 Introduction

In today's rapidly evolving energy landscape, the transparent and reliable communication of model inputs and outputs is more crucial than ever. Energy system analyses increasingly inform major policy decisions and long-term investments. This makes it essential to trace, understand, and contextualize model data for both modelers and external stakeholders.

Energy system models like TIMES rely on vast, diverse datasets that evolve over time, are sourced from various references, and often undergo multiple rounds of modification by different users. Traditionally, the TIMES modeling workflow has focused primarily on ensuring input data consistency, while the documentation of its provenance and version history has largely been an external or manual process.

While making model structures and assumptions more transparent is a meaningful step, it is insufficient on its own. Models like TIMES remain inherently complex, and without clear and consistent information about the sources, classifications, and meanings of each data point, stakeholders often struggle to fully interpret or trust the results.

As the scale and complexity of models increase, involving numerous collaborators, large public datasets, national statistics, technology roadmaps, and proprietary information, the traceability and accountability of input data become even more critical. Key challenges observed in practice include:

- **Loss of Data Provenance:** Once entered into the model, the original source, author, or method of derivation for specific data points can become difficult or impossible to reconstruct.
- **Version Control Issues:** Updates to input parameters (e.g., costs, efficiencies) often overwrite previous values without clear records of what changed, why, or when.
- **Inconsistent Documentation:** Metadata (such as source, authorship, and comments) is often scattered across emails, spreadsheets, or supplementary documents, rather than embedded within the modeling workflow.
- **Collaboration Difficulties:** As more users contribute to a model, the lack of embedded metadata complicates attribution of inputs to contributors, impeding quality assurance and governance.

These challenges not only hinder model maintenance but also diminish the credibility, auditability, and reusability of TIMES models in both research and policy-making contexts. Metadata remains underutilized within the ETSAP community and beyond. Although valuable metadata often emerges during data collection (e.g., sourcing technology parameters or defining policy scenarios), it is typically tracked in ad-hoc spreadsheets or disconnected documentation, rarely integrated systematically into model databases. Consequently, opportunities to improve transparency, collaboration, quality assurance, and long-term maintainability are often missed.

To address these challenges and opportunities systematically, a new metadata tagging system is developed for integration into the VEDA data environment. Recognizing the limitations outlined above, this new feature embeds metadata directly into TIMES model input files and databases using a standardized and flexible approach. By designing a metadata structure compatible with Excel input templates and VEDA workflows, our goal is to:

- Embed critical contextual information directly alongside model data in a structured, machine-readable format.
- Enable the tracking of data origin, authorship, version, and modification history at a detailed level.
- Enhance transparency for model users, reviewers, and stakeholders.
- Lay the foundation for improved quality control, collaboration, and reproducibility practices.

To assess the feasibility and usability of the proposed metadata system, a small Proof-of-Concept (POC) exercise was conducted using the TIMES Demo model. The following sections describe the design, implementation, and findings from this POC.

2 Metadata Framework in VEDA

Metadata Dimensions

Metadata dimensions specify which descriptive attributes VEDA will store and display for each tagged element. Administrators configure these dimensions in SysSettings, within a dedicated table named `~md_dimensions`. Each record in this table defines:

- the **name** of the metadata dimension, and
- whether it should **overwrite** values inherited from broader scopes (e.g., workbook → worksheet → column → row).

While users may introduce any number of custom dimensions, the field comment is always included by default. If no dimensions are explicitly declared in the SysSettings table, comment will automatically be added as the default metadata dimension, encompassing all metadata entries. Below is an example of a properly configured `~md_dimensions` table:

<i>~md_dimensions</i>	
<i>dimension</i>	<i>overwrite</i>
<i>date</i>	Y
<i>author</i>	Y
<i>version</i>	Y
<i>source</i>	Y
<i>year</i>	Y
<i>publisher</i>	Y
URL	Y
comment	

Metadata Tags

The syntax for metadata tags follows the pattern: `~md-<element>_<scope>`, where `md` denotes metadata. The `<element>` refers to the item being tagged (e.g., value, technology, commodity), and `<scope>` indicates the level at which the metadata is applied (e.g., workbook, worksheet, row, column, table). The newly introduced metadata tags, described below, enable users to associate metadata with various scopes in a structured and flexible manner:

- Data Values:
 - `~md-v_w`: workbook; `~md-v_s`: worksheet; `~md-v_r`: row; `~md-v_c`: column; `~md-v_tr`: table(s) - in the same row as the table tag itself; `~md-v_tc`: table(s) - in the same column as the table tag itself
- Technologies:
 - `~md-t_w`; `~md-t_s`; `~md-t_r`; `~md-t_c`
- Commodities:
 - `~md-c_w`; `~md-c_s`; `~md-c_r`; `~md-c_c`

Metadata Syntax

Metadata entries follow this structure of `<dimension>: <metadata>; <dimension>: <metadata>; ...` (e.g., `author: Pieter Vin; source: IEA 2023; version: 1.2; date: 2025-03-01`)

This string can be distributed across contiguous cells; however, at least one dimension metadata entry must be included in the same cell as the metadata tag. It is worth noting that metadata tags must match the type of input within the input files. For example, using `~md-c_s` in a worksheet that contains only technology-related inputs—such as those tagged with `~FI_T` will not be effective, as the metadata scope does not match the nature of the input.

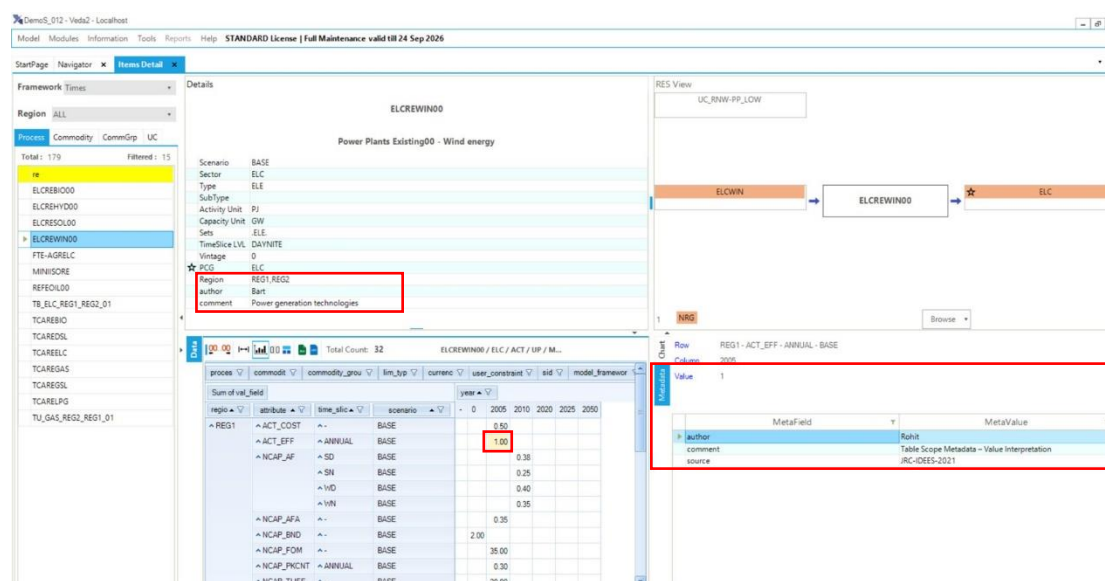
Overriding and Hierarchy

When multiple scopes apply to the same cell:

- Metadata hierarchy defines which scope overrides another: `workbook (_w)` → `worksheet (_s)` → `table(s) in the same column (_tc)` → `column (_c)` → `table(s) in the same row (_tr)` → `row (_r)`. For instance, if 'source' dimension is defined at worksheet and row levels, the row-level metadata applies.
- Comments are concatenated instead of overwritten.

Display and Browsing

Metadata information is displayed alongside data entries when you select (click) the specific data item for which you want to view the associated metadata. In addition, metadata related to the introduction of commodities and technologies is shown in the Details sub-window of the Item Details module. The graph below illustrates this.



3 POC Design: Demo Model Adaptation

With the metadata framework defined, the next step was to test its application in a real model environment. The demonstration file *VT_REG1_ELC_V12.xlsx* illustrates metadata tagging. It contains example tags in different scopes. The Metadata_PoC worksheet lists tag locations and content for educational purposes.

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Note: This file is primarily intended for demonstration purposes and can be executed within the demonstration model *DemoS_012*.