InterCAX LLC

75 Fifth Street NW, Suite 213
Atlanta, GA 30308, USA
Voice: +1-404-592-6897
Web: www.InterCAX.com
E-mail: info@intercax.com

# Using ParaMagic for Integrating Legacy Models with SysML

Dr. Dirk Zwemer
InterCAX LLC

## Abstract

Most organizations develop a variety of models in a variety of modeling and simulation tools to describe parts of their system and have made significant investments in developing and validating those models. SysML parametrics offers an efficient and straightforward approach to integrating these legacy models as part of a larger system model. In this application note, we illustrate how the ParaMagic plug-in for MagicDraw can tie together economic, environmental, and cost models implemented in MATLAB® in a SysML model describing a regional energy system. SysML parametrics allow key variables such as price and demand to be exchanged between models, while detailed calculations are performed within modular MATLAB functions. Microsoft Excel® is used to feed initial conditions into the MagicDraw model and to report and graph results.

## Introduction

SysML has the ability to fully define all the parametric relationships in a system. In other words, each mathematical relationship between system properties can be captured as a mathematical expression in a constraint block. The parametric expressions can be exported to an equation solver by a tool such as ParaMagic for purposes of system simulation, analysis, requirements checking, etc.

But there are at least two reasons why this is not always the best approach

- Teams frequently already have legacy simulation and analysis models in other software tools or languages which capture part of the system's behavior. These legacy models may embody man-years of effort in development and verification, and reproducing them in SysML may be hard to justify.
- Graphical programming approaches such as SysML parametrics are generally not an efficient method for highly complex computations. High level languages and tools such as MATLAB and Mathematica are much faster for calculations with multiple lines of equations.

The alternate approach is to use SysML parametrics as an integration framework for existing simulation and analysis models in other tools, as "glue" in binding these models together. This offers several advantages.

- Legacy models with known behavior and validity can be re-used
- Specialist tools, e.g. discrete event simulators, can be used with SysML
- High-level relationships between models can be represented graphically for ease of understanding
- Simple transformations, for example, unit conversions, between legacy models can be incorporated as SysML parametrics
- Simple “rule of thumb” parametric equations used in early versions of the model can be replaced by more sophisticated external models as system development matures
- Parametric relationships between different levels of the system structure, e.g. the weight of the system is equal to the sum of the weights of the subsystems, can be captured in the system architecture even before the number of subsystems is specified.
- Spreadsheets can be configured as a consistent I/O mechanism for the system model as a whole.

## The System

The system to be modeled is a regional energy system, as might be developed by a utility company. Such as system would have a supply component and a demand component, and might be designed to answer three broad questions

- What is the impact of company decisions on the company’s profitability?
- What is the impact on the regional economy?
- What is the impact on the regional environment?

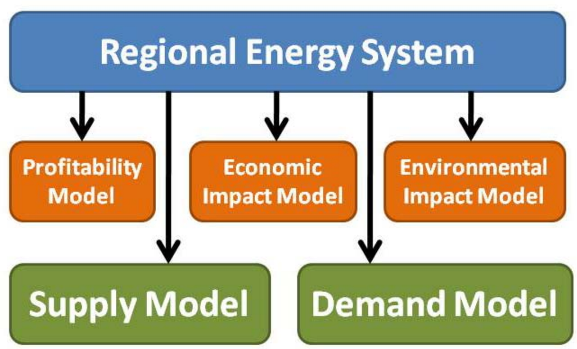


Figure 1 Regional Energy Model

Furthermore, the company has five existing models painstakingly developed over many years

1. Energy_cost ($/kW-hr for a specific generating plant) = f[power output (MW), capacity (MW), plant lifetime (Yr), variable cost ($/kW-hr), fixed cost (M$/yr), capacity cost ($/kW)]
2. Environmental_cost ($/kW-hr for a specific generating plant) = f[power output (MW), capacity (MW), plant lifetime (Yr), atmospheric emissions cost ($/kW-hr), solid emissions cost ($/kW-hr), water use cost ($/kW-hr), environmental cost of capacity ($/kW)]
3. Demand (MW) = f[price ($/kW-hr), base price($/kW-hr), industrial elasticity, industrial base demand (MW), consumer elasticity, consumer base demand (MW)]
4. Economic_impact (arbitrary units, normalized to 100 for initial data set) = f[supply (MW), demand (MW), Total_environmental_cost ($/kW-hr)]

5. Environmental_impact (arbitrary units, normalized to 100 for initial data set) = f[supply (MW), Total_environmental_cost ($/kW-hr)]

In our example, each of these models is packaged as a MATLAB function. ParaMagic can also interface to MATLAB scripts, Simulink models (through MATLAB scripts), Mathematica functions and MS Excel spreadsheets. Other interfaces are under development.

Comparison of the five legacy models with Figure 1 shows several good correspondences, but also several missing pieces.

1. The energy cost and environmental cost models are for individual generating plants. We need to calculate total output power (supply) and the weighted average energy cost and environmental cost for the entire supply system, containing an unknown number of generating plants.
2. We need to calculate price and profitability. Until more sophisticated models are available, we will use simple parametric equations in our model

   **Price ($/kW-hr) = Cost ($/kW-hr) * (1 + ProfitFactor)** where ProfitFactor is a fixed mark-up

   **Profit (M$/yr) = (ProfitFactor * Cost ($/kW-hr) * Demand (MW) + (GridPrice ($/kW-hr) – Cost ($/kW-hr)) * (Supply (MW) – Demand (MW)) * 8.76** where GridPrice is the price of energy from outside the regional system. This equation assumes excess supply can be sold to the grid and excess demand can be purchased from the grid.

3. Certain properties, including price, cost, environmental cost, supply and demand, must be exchanged between models via the Regional Energy Model Block via parametric relationships. We will also copy, profitability, economic impact and environmental impact results up to this block, primarily to make those key results easier to find and report.

The final SysML model containing all these elements is shown in Figures 2 and 3.

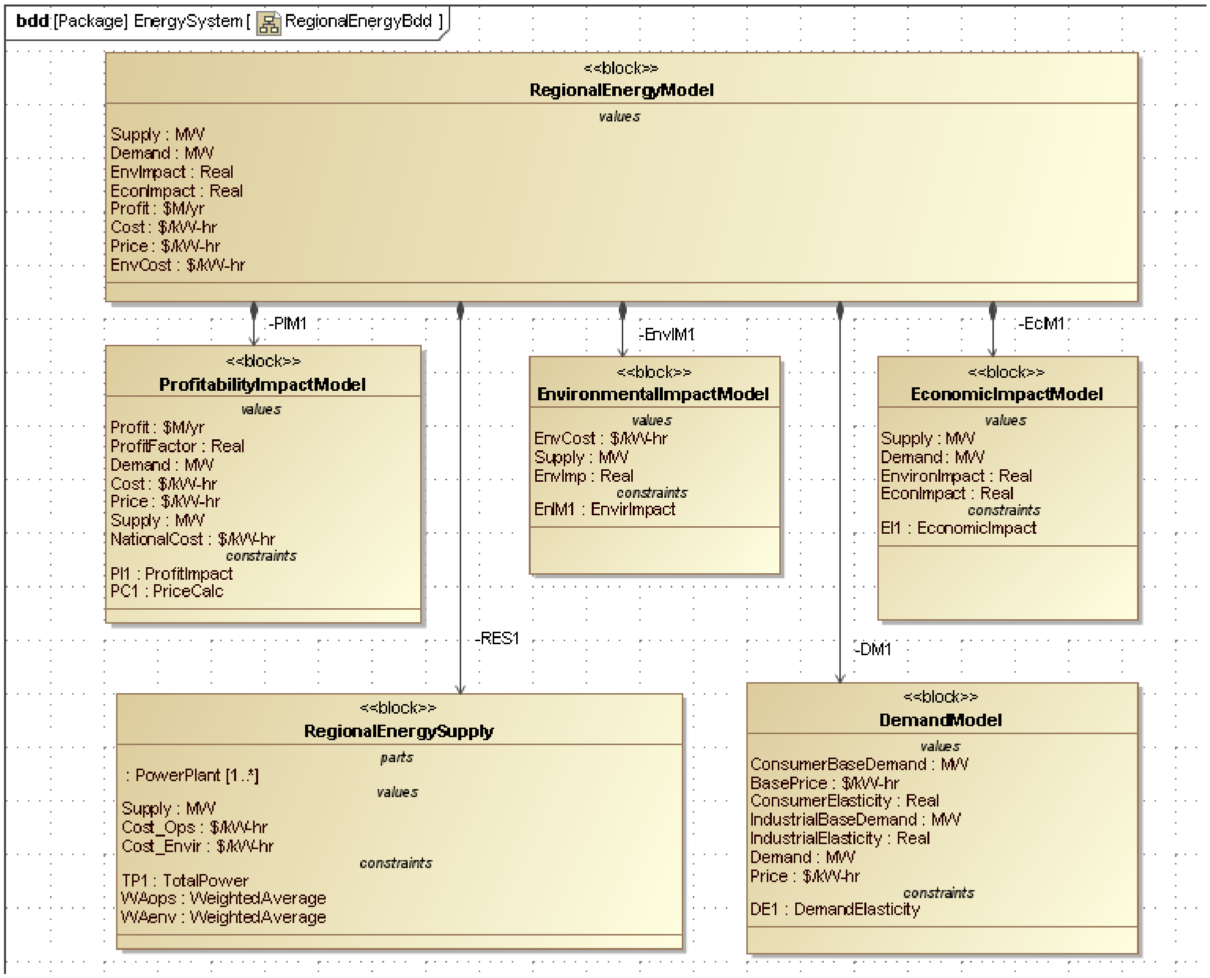


Figure 2  Regional Energy Block Definition Diagram, Part 1

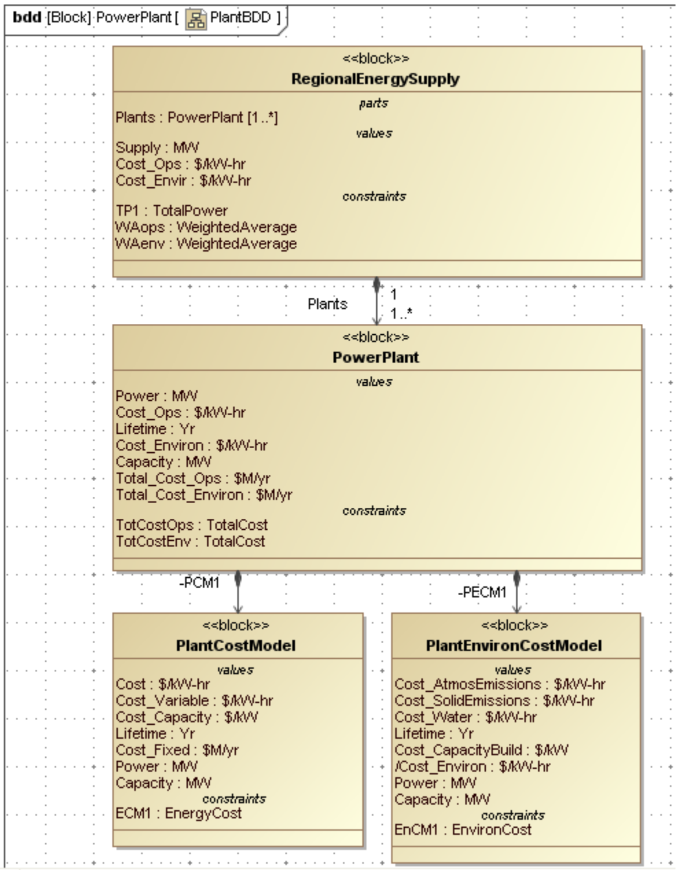

Figure 3  Regional Energy Block Definition Diagram, Part 2

Figure 2 is very similar to Figure 1 with the properties and constraints added. We will describe these constraints more in the next section.

Figure 3 displays the breakdown of the Regional Energy Supply block. It owns an indeterminate number of generating plants, which is shown by the connecting arrow between RegionalEnergySupply and PowerPlantwith the label “1..*” next to PowerPlant. “1..*” represents a multiplicity of one to many. The precise number of plants will only need to be specified when a model instance is created.

## The SysML Parametric Model

Parametric diagrams capture relationships between properties of the structural elements of a SysML model. In this example, we use these relationships (constraints) in three ways:

- To wrap external models (MATLAB functions)
- To capture equation-based relationships between properties
- To share properties between models

Figure 4 shows an example of the first type. The constraint property EnIM1:EnvirImpact contains the constraint

Envimp = xfwExternal(matlab, function, environimpact, p, ec)

which calls the MATLAB function “environimpact.m” with input arguments p and ec that match the function inputs and returns a value for the environmental impact. The other four legacy models are treated in the same way.

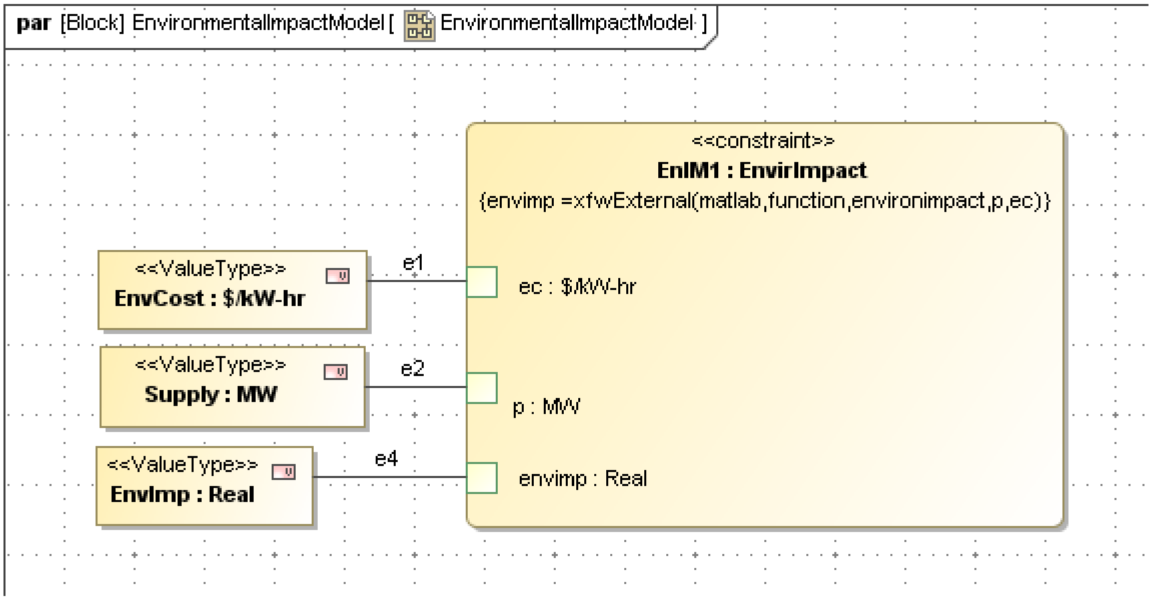


Figure 4 Energy Model Parametric Diagram – External function call

Within the Regional Energy Supply model, we need to calculate the total power output and the weighted average energy cost and environmental cost from all generating plants, which is shown in Figure 5. Rather than specify two, three, or some other number of plants, we allow the Plants part property to have a multiplicity from 1 to many (1..*). The sum function in TotalPower will calculate the sum of the Power property from all plants belonging to the supply model, however many are specified at the Instance stage.

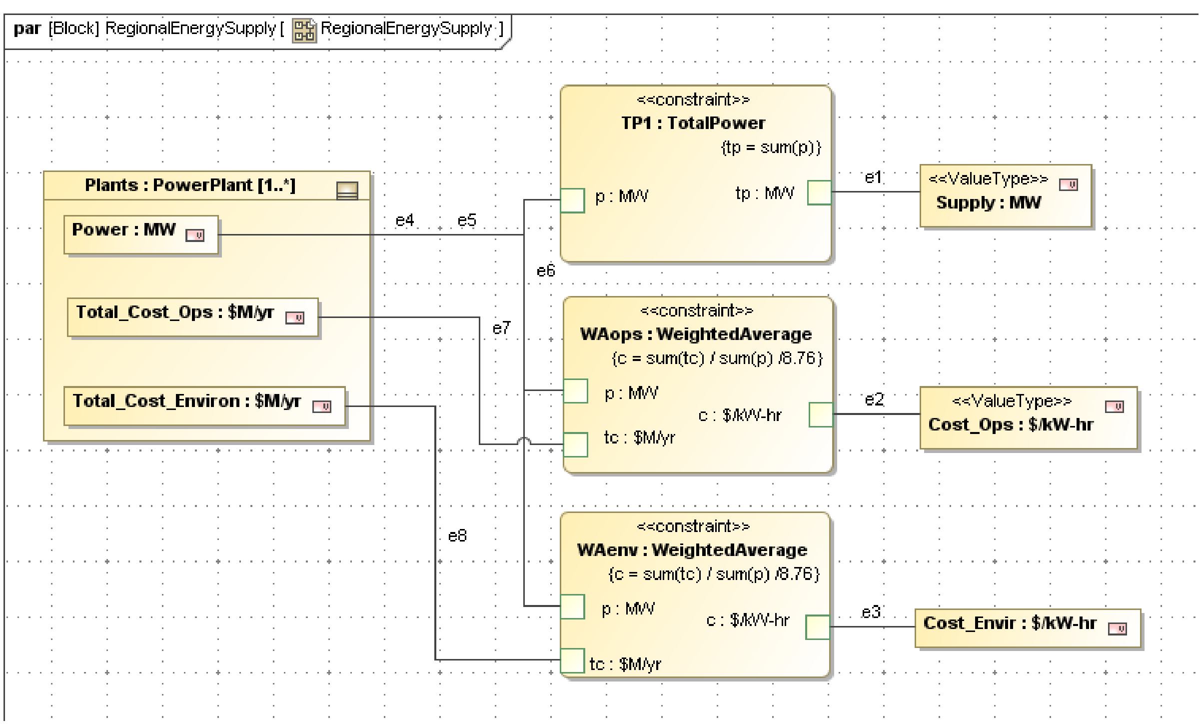


Figure 5 Energy Model Parametric Diagram – Complex aggregate relationships

Similar calculations are performed for the weighted averages. These are referred to as "complex aggregate" calculations because they apply to lists of the structure {Plant1.Power, Plant2.Power,…}.

Finally, some parametric diagrams show how models are tied together through equalities. The parametric diagram in Figure 6 belongs to the top level block, Regional Energy Model. The properties of this block, shown at the bottom, are tied to equivalent properties in the Profitability, Economic Impact and Environmental Impact submodels. For example, the property Supply, which is calculated in the Regional Energy Supply block, is tied to Supply in the Regional Energy Model (not shown), where it is further tied to Supply in the other submodels, where it is used as an input for calculating profitability, economic impact, and so forth. This is not the only way to organize the model, but it helps keep the different submodels more modular.

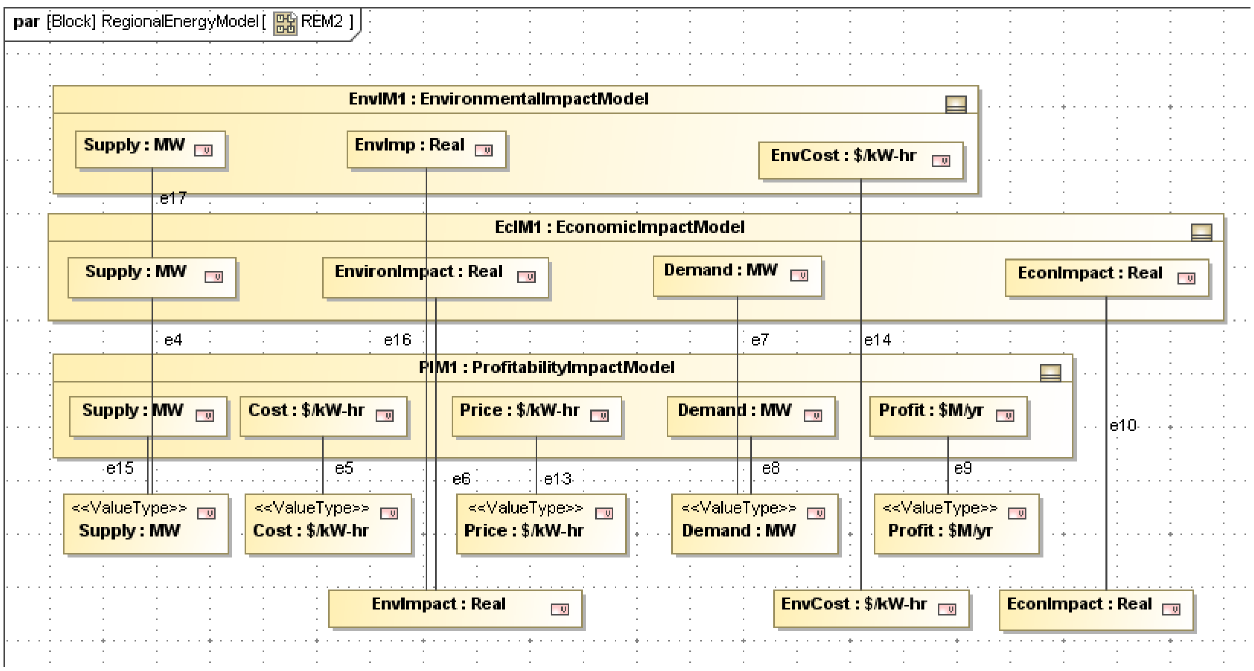


Figure 6 Energy Model Parametric Diagram – Sharing Pa

## Running Simulations on the Energy Model

Parametric calculations are applied to instances of the SysML model. The ParaMagic plug-in for MagicDraw takes the parametric relationships in the model plus the specific numbers assigned in the instance, exports them as a set of equations to a mathematical solver, and returns the solutions to the SysML model instance. ParaMagic also allows SysML model instances to read and write data from MS Excel spreadsheets and we will use the more compact Excel tables to display the givens and results, rather than pictures of instance diagrams or the ParaMagic browser.

We start by creating an instance diagram with three generating plants: Coal, Nuclear, and Solar. For each plant, we require ten properties, which are organized in the worksheet shown in Figure 7. We also need some additional inputs for the Demand and Profitability models, which are shown at the top of Figure 8. There are seven output parameters of interest shown at the bottom of Figure 8.

Energy4.xlsx

| | A | B | C | D | E |
|---|---|---|---|---|---|
| 1 | | | Plant 1 | Plant 2 | Plant 3 |
| 2 | | | Coal | Nuclear | Solar |
| 3 | Type | | | | |
| 4 | Capacity | MW | 200 | 500 | 50 |
| 5 | Power Output | MW | 200 | 500 | 50 |
| 6 | Lifetime | Year | 10 | 20 | 5 |
| 7 | | | | | |
| 8 | Variable Cost | $/kW-hr | 0.02 | 0.007 | 0.001 |
| 9 | Fixed Cost | $M/yr | 1 | 3 | 0.5 |
| 10 | Capital Cost | $/kW | 500 | 5000 | 2000 |
| 11 | | | | | |
| 12 | Atmospheric Emissions Cost | $/kW-hr | 0.02 | 0.005 | 0 |
| 13 | Solid Emissions Cost | $/kW-hr | 0.001 | 0.02 | 0 |
| 14 | Water Usage Cost | $/kW-hr | 0 | 0.01 | 0 |
| 15 | Capacity Environmental Cost | $/kW | 100 | 150 | 300 |
| 16 | | | | | |

Figure 7  Input Parameters for Energy Model

| | | | |
|---|---|---|---|
| 2 | **Inputs** | | |
| 3 | Profitability Inputs | | |
| 4 | Profit factor | | 0.05 |
| 5 | National Grid Price | $/kW-hr | 0.035 |
| 6 | | | |
| 7 | Demand Inputs | | |
| 8 | Consumer Base Demand | MW | 400 |
| 9 | Consumer Elasticity | | 1 |
| 10 | Industrial Base Demand | MW | 300 |
| 11 | Industrial Elasticity | | 2 |
| 12 | | | |
| 13 | **Results** | | |
| 14 | Supply | MW | |
| 15 | Demand | MW | |
| 16 | Cost | $/kW-hr | |
| 17 | Price | $/kW-hr | |
| 18 | Profit | $M/yr | |
| 19 | Economic Impact | index 100 | |
| 20 | Environmental Impact | index 100 | |

Figure 8  Input and Output Parameters for Energy Model

The process for running the simulation has three steps.

1. Read inputs from the spreadsheet
2. Run the ParaMagic browser
3. Write the results to the spreadsheet.

The initial results are shown in Figure 9.

| | | | |
|---|---|---|---|
| 13 | **Results** | | |
| 14 | Supply | MW | 750.0 |
| 15 | Demand | MW | 653.7 |
| 16 | Cost | $/kW-hr | 0.0337 |
| 17 | Price | $/kW-hr | 0.3530 |
| 18 | Profit | $M/yr | 10.8 |
| 19 | Economic Impact | index 100 | 99.9 |
| 20 | Environmental Impact | index 100 | 100.0 |

Figure 9  Results for initial input parameter set

We note that supply from the system's generating plants exceeds demand by almost 100 MW.  One interesting question is to ask what happens if we throttle back supply by 100 MW, reducing either the coal or nuclear plant output.  Results from such a trade study are shown in Figure 10 and 11.

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 13 | **Results** | | | | | | | |
| 14 | Supply | MW | 750.0 | 730.0 | 710.0 | 690.0 | 670.0 | 650.0 |
| 15 | Demand | MW | 653.7 | 643.8 | 633.8 | 623.5 | 613.0 | 602.3 |
| 16 | Cost | $/kW-hr | 0.0337 | 0.3400 | 0.3440 | 0.0348 | 0.3530 | 0.0358 |
| 17 | Price | $/kW-hr | 0.3530 | 0.3570 | 0.3610 | 0.0366 | 0.0371 | 0.0375 |
| 18 | Profit | $M/yr | 10.8 | 10.3 | 9.9 | 9.6 | 9.3 | 9.1 |
| 19 | Economic Impact | index 100 | 99.9 | 98.0 | 96.1 | 94.2 | 92.3 | 90.4 |
| 20 | Environmental Impact | index 100 | 100.0 | 103.8 | 107.8 | 112.1 | 116.6 | 121.4 |
| 21 | | | | | | | | |
| 22 | CoalPower | MW | 200.0 | 180.0 | 160.0 | 140.0 | 120.0 | 100.0 |
| 23 | | | | | | | | |
| 24 | **Results** | | | | | | | |
| 25 | Supply | MW | 750.0 | 730.0 | 710.0 | 690.0 | 670.0 | 650.0 |
| 26 | Demand | MW | 653.7 | 634.7 | 616.0 | 597.4 | 579.1 | 560.8 |
| 27 | Cost | $/kW-hr | 0.0337 | 0.0344 | 0.0352 | 0.0360 | 0.0368 | 0.3780 |
| 28 | Price | $/kW-hr | 0. 353 | 0.0361 | 0.0369 | 0.0378 | 0.0387 | 0.3960 |
| 29 | Profit | $M/yr | 10.8 | 10.1 | 9.4 | 8.6 | 7.9 | 7.2 |
| 30 | Economic Impact | index 100 | 99.9 | 97.9 | 95.8 | 93.9 | 92.1 | 90.3 |
| 31 | Environmental Impact | index 100 | 100.0 | 106.5 | 113.6 | 121.4 | 130.1 | 139.8 |
| 32 | | | | | | | | |
| 33 | NuclearPower | MW | 500.0 | 480.0 | 460.0 | 440.0 | 420.0 | 400.0 |

Figure 10  Results for trade study – Reducing output from Coal plant (top) and Nuclear Plant (bottom)

Reducing output increases cost on a per kW-hr basis (because fixed and capacity costs are spread over a smaller base).  Increased cost and price reduce demand and system profitability.  All these factors have a negative impact on the local economy.  However, as shown in Figure 11, environmental impact is positive for reducing either coal or nuclear output (more positive for nuclear cutbacks) because these plants are assigned higher environmental costs than solar.

Note: The numbers reported are purely for purposes of demonstrating the use of SysML parametrics. Neither the input values nor the models themselves are offered as valid for actual energy systems.

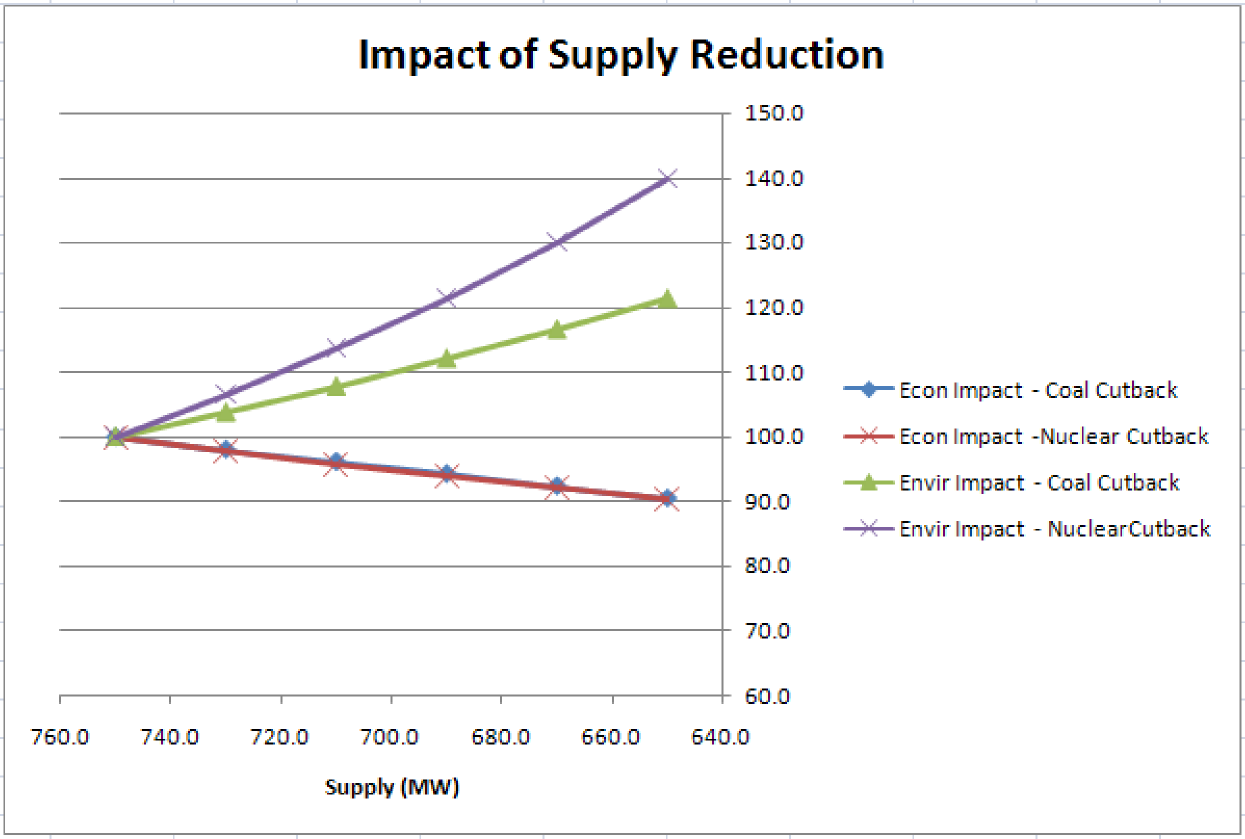


Figure 11 Results for trade study – Economic and Environmental Impact

## Discussion

We've attempted to demonstrate how using SysML parametrics to integrate legacy models can combine the power of proven models and specialized simulation tools with the high-level visualization and collaboration advantages of model-based systems engineering. Several directions for future development appear.

1. Interfaces to more simulation tools and models would be valuable, including C++ and Java code modules, discrete event simulators, CAE tools like FEM and CFD, and many others.
2. Some self-directed optimization mechanism that automatically seeks a solution that meets all requirements would be very desirable. Multi-variable optimization is a difficult problem, but mechanisms for efficiently exploring the design space (trade studies, design of experiments) are needed.
3. Structural and parametric diagrams lend themselves to static or equilibrium analyses, but time-based simulations, especially time-synched simulation across multiple models, requires significant technology development.