

# I3M/SESDE 2013 BEST PAPER AWARD

The 10<sup>th</sup> International Multidisciplinary Modeling & Simulation Multiconference (I3M)  
International Workshop on Simulation for Energy, Sustainable Development & Environment (SESDE)  
September 25-27, 2013. Athens, Greece.

## ECO-BOND GRAPHS: AN ENERGY-BASED MODELING FRAMEWORK FOR COMPLEX DYNAMIC SYSTEMS WITH A FOCUS ON SUSTAINABILITY AND EMBODIED ENERGY FLOWS

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**ABSTRACT:** This article presents a general methodology for modeling complex dynamic systems, focusing on sustainability properties that emerge from tracking energy flows. We adopt the embodied energy (*emergy*) concept that traces all energy transformations required for running a process. Energy can therefore be studied in terms of all energy previously invested up to the primary sources, and sustainability can be analyzed structurally. These ideas were implemented in the bond graph framework, a modeling paradigm where variables are explicitly checked for adherence to energy conservation principles. We introduced the new Ecological Bond Graphs (EcoBG) along with the EcoBondLib Modelica library. EcoBG represent systems in a three-faceted fashion, describing dynamics at their mass, energy, and *emergy* facets. EcoBG offers a scalable formalism for the description of *emergy dynamic* equations (resolving some mathematical difficulties present in their original formulation) and new capabilities for detecting unsustainable phases not automatically discovered when using the *emergy* technique alone.



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The 10th International Multidisciplinary Modelling & Simulation  
Multiconference  
I3M 2013



BEST PAPER AWARD

Presented to  
THE 1ST INTERNATIONAL WORKSHOP ON SIMULATION FOR ENERGY, SUSTAINABLE DEVELOPMENT & ENVIRONMENT

PAPER TITLE:

"Eco-bond graphs: an energy-based modeling framework for complex dynamic systems with a focus on sustainability and embodied energy flows"

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SESDE 2013 General Co-Chairs

September 2013  
Athens, Greece



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