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OsmoseLua – An Integrated Approach to Energy Systems Integration with LCIA and GIS

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Abstract

In this paper, we present our recent work on the implementation of an Energy Systems Integration platform allowing the modeling of Energy Systems integrating LCI (Life Cycle Inventory), LCIA (Life Cycle Impact Assessment) and GIS (Geographical Information Systems) data as modeling parameters and variables included in an industrial process model.

Based on our previous experience in methodologies and models of Energy Systems Integrations, we developed a new generation of the platform using the script language Lua. The main motivation for choosing Lua was to radically improve the performance of the system, which was the main drawback of the existing Matlab-based system, while proposing a more convenient way of describing the modeling elements and their combination.

The second objective of our work was to integrate LCI and LCIA aspects as a generic part of the Energy Systems modeling methodology. We are currently working on the process data mapping algorithm in order to match the appropriate Unit process and Elementary flows identifiers used in the ecoinvent v3 database.

Thirdly, by having the possibility of importing GIS databases (in csv format), some coordination data, such as longitude and latitude, can be directly included as Energy System elements' location parameters. This possibility improves the efficiency in modeling the energy integration of urban systems.

Keywords: process system engineering, energy integration, LCA, Lua, OSMOSE

1. Introduction

Many different modeling environments (e.g. MATLAB®, GAMS®, AMPL®, gPROMS®, BELSIM®) and commercial solvers (e.g. GLPK®, CPLEX®) exist for process system engineering (Martin, 2015). One of the biggest challenges is to handle the communication among them, while performing design and optimization of the overall system. With this in mind, the OSMOSE® platform was designed in the Laboratory of Industrial Energy Systems (LENI software, 2005) at EPFL as a flexible and robust tool for the design of complex integrated energy systems in a Matlab environment.

Figure 1 illustrates the methodology implemented in OSMOSE® for the design and optimization of energy systems. Energy systems are generally Mixed-Integer Non Linear Programming (MINLP) models with multiple conflicting objectives (e.g. economic, thermodynamic and environmental indicators). Following a two-stage decomposition strategy the problem is divided into a master problem and a slave sub-problem (Gerber et al. 2013, Weber, 2008). The master problem is solved using a

Queueing Multi-Objective Optimization (QMOO) technique (Leyland 2002). QMOO is a robust evolutionary algorithm designed at EPFL to find the global optimum together with many local sub-optimal solutions. This is important as it provides the decision maker with many possibilities. The slave sub-problem is a Mixed-Integer Linear Programming (MILP) model solved by using a branch-and-bound algorithm. In the Matlab-based platform, the LCA database was based on ecoinvent version 2.2.

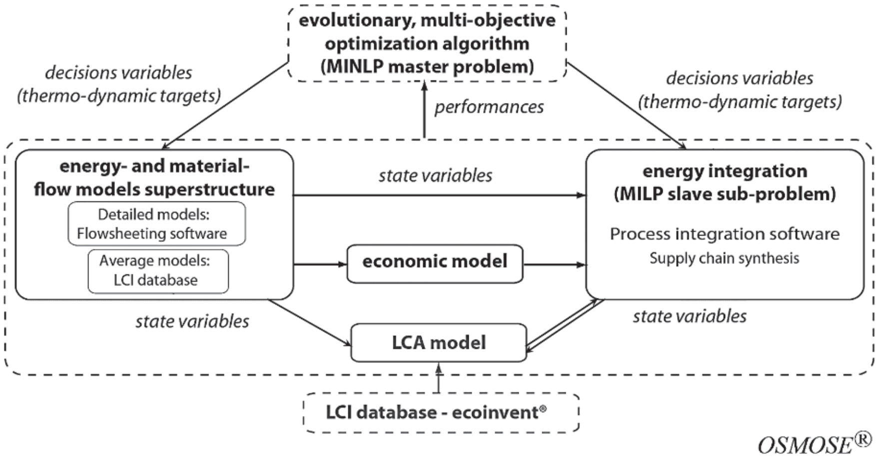

Figure 1. OSMOSE computational framework for energy system optimization. Adapted from (Gerber et al., 2013)

2. OSMOSE Generation II - OsmoseLua

Based on our previous experience with the OSMOSE methodology, we developed a new approach using the script language Lua (Ierusalimschy, 2013). As a first step, the slave sub-problem of OSMOSE was handled while integrating GLPK and Belsim-Vali for solving MILP problems. We are continuing to complement the multi-objective optimization algorithm in Lua. The main motivation for choosing Lua was to radically improve the performance of the system, which was the main drawback of the existing Matlab-based system, while proposing a more convenient way of describing the modeling elements and their combination.

Another important feature of the Lua version of OSMOSE is its extensibility and ease of integration (Figure 2). This was taken into consideration while designing the core architecture. The interface part depicted as GenericFrontend and GUI in Figure 2 is the user interfacing API either on the users' stationary computing environment or on portable devices. Due to the Lua language's portability and small footprint, the integration on mobile devices for model search and results consultation is strongly encouraged as our future development plan.

Finally, while implementing the OSMOSE core part in Lua, we redesigned the LCI and LCIA parts as pluggable and extensible generic SW modules rather than integrating the LCA database as part of the energy and material structures as depicted in Figure 1. Consequently, in the currently available OsmoseLua architecture we provide two types of library elements: on the one hand the Energy process model ((1) in Figure 1); and on the other hand the associated LCA dataset model ((2) in Figure 1) where both are generic and reusable. The main advantage of such improvement is twofold: i) firstly, modelers can achieve a more detailed analysis while including LCI material flows and/or life cycle impact assessment separately or jointly. ii) secondly, the evolution of both model parts can be dealt with independently by modifying the process model without changing the LCA aspects, or inversely by updating only the LCA database.

In the following section we discuss LCI and LCIA principles in more detail.

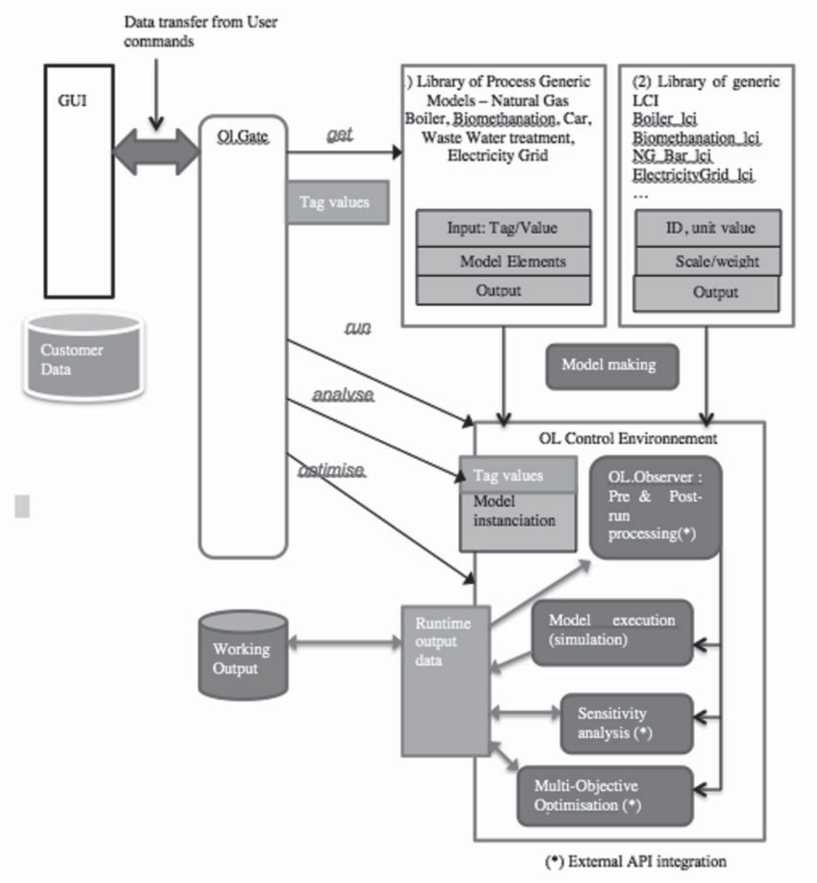

Figure 2. Global overview of OsmoseLua architecture

3. LCI and LCIA with ecoinvent version 3.1

Life cycle assessment (LCA) is the evaluation of environmental impacts over the life cycle of a product, process or activity, from the extraction of raw materials to the end-of-life. LCA can be used to identify opportunities to reduce environmental impacts of a product, to inform decision makers in order to aid in strategic planning and design, to select relevant indicators based on environmental performance and/or for marketing purposes (ISO 2006).

In our work, one of the objectives is to integrate life cycle inventory (LCI) and life cycle impact assessment (LCIA) into the energy systems modeling methodology. The database ecoinvent version 3.1 was used for the integration of energy modeling variables accessible for the optimization modeling (Weidema et al. 2013). As done by Gerber et al. (2013), energy flows such as fuel or electricity consumption are modeled by associating with each flow a corresponding LCI ecoinvent unit process. Likewise, material flows and flows are modeled in this manner. Direct emissions are modeled by associating with each flow a corresponding elementary flow, again from the ecoinvent database. A general representation of the above methodology is shown in Figure 3. Care is taken to avoid double counting of emissions; if an emission is already included in the unit process, then the same emission is not modeled with an elementary flow.

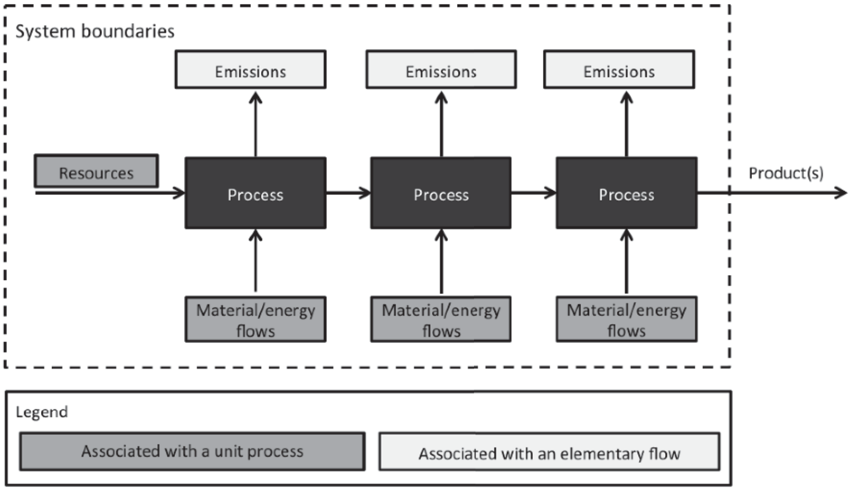

Figure 3. General representation for association of material/energy flows and resources with unit processes and emissions with elementary flows.

Different LCA methods (e.g. IMPACT 2002+) and indicators can be used for the impact assessment, to be included in the energy optimization. LCIA results are obtained by multiplying life cycle inventory flows with the appropriate characterization factor for each inventory flow. This results in environmental impacts for different midpoint categories such as, Global warming, Aquatic eutrophication, Respiratory effects, etc. One or more environmental indicator(s) may be considered as an objective function in the optimization.

In the following section, OsmoseLua application architecture is presented which includes a discussion of LCIA pluggable architecture.

4. OsmoseLua generic architecture

4.1. LCA plug-in model

We modeled the LCA dataset as a distinguishable part of the process model definition while cutting off the tight-coupling relationship in the previous approach (Figure1). The separated LCA dataset was then modeled as Lua module definitions for data construction and necessary functions for scaling and weighting factor setting.

One of the advantages of a loosely coupled LCA model is that, if the modeler has no detailed information of its energy process model, the modeler can reference existing LCA elements from the LCA libraries which provide a set of generic databases while selecting a similar energy process model. The OsmoseLua plug-in then provides methods for further specialization of dataset elements. The scaling and weight factors are implemented as LCA dataset parameters which can be customized according to the target model.

When applying impact assessment methods, two types of identifiers were taken considered: Unit process IDs, based on ecoinvent v2.2 and Activity IDs based on ecoinvent v3. This requirement is for recovering all the available Energy Processing Models and previously defined LCA datasets declared within each Model element. As we are in the transition phase from ecoinvent v2.2 to ecoinvent v3, this method will allow us to reuse our existing LCA database of models. Such cross-referencing is possible now with our OsmoseLua LCA plugins.

4.2. Integration of GIS information

One evolving aspect with OsmoseLua is its way of handling GIS data from a standard file format and recovering values as state information of energy model superstructure. By having the possibility of importing GIS databases (in csv format as a first trial), data such as longitude and latitude can be directly included as Energy System elements' location parameters. This improves the efficiency of modeling urban systems energy integration, where building locations or heights are often necessary as a constituent of the modeling units.

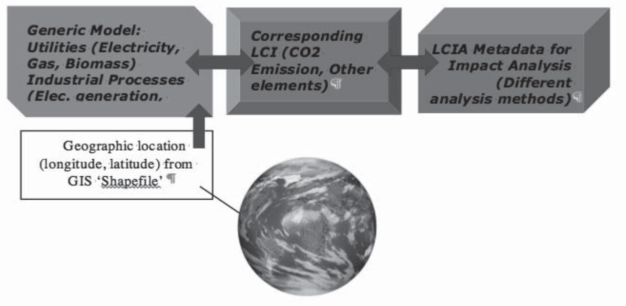

Figure 4. Overall relationship between GIS data handling and LCI-LCIA plug-in in OsmoseLua .

4.3. Validation

In the context of the project PFE3 (PFE3), two case studies are studied among project partners for the purpose of validating the modeling approach and the technical feasibility. One case study considers a hypothetical system with a population of 450'000 inhabitants including four categories of energy services: space heating, domestic hot water production, electricity and transport. Waste treatment includes municipal solid waste, organic waste and wastewater. Four industries are studied: a sawmill, a greenhouse producing vegetables, an industrial laundry service and a bio-refinery. A baseline model of the mentioned case study was implemented and analyzed in the Matlab version of. Afterward, the same conceptual model was re-written, as a proof-of-concept example, in the OsmoseLua environment and similar energy integration results were obtained. The life cycle impact assessment was analyzed with the IMPACT 2002+ method.

5. Conclusions

Throughout the implementation phase in Lua, we recognized that Lua made it easy to achieve the implementation of new sub-systems, such as a GIS data handler, LCA dataset integration and LCIA meta tables. It is due to the Lua language feature which is suitable for rapid prototyping and developing high level domain specific languages (DSL).

Currently, other partners of the project are working on a Java-based User interface layer for the purpose of customizing and integrating visualized GIS integration.

A future objective is to include the customization of the Generic Frontend layer on a mobile application environment. Lua is a popular language for many types of application developments on portable devices and game development. The Lua community provides a rich set of specialized IDE tools almost all of which are freely available.

It would be of interest to use and integrate a specialized tool such as OpenLCA into OsmoseLua. In this case, it might become more efficient to construct a new LCA dataset starting from process system specifications to be studied. An important benefit of such a tool is the possibility of composing a new process model and life cycle impact matrix with the capability of exporting/importing standard data formats such as XML, csv or database files. With OpenLca, such kind of process composition and data exportation is possible using executable system libraries. In this case, the exported dataset from OpenLCA under the XML format, for example, would be directly interpreted by the Lua LCA data handler and can be used in combination with other parts of our Lua LCA plug-in.

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