Demo: The EAM Environmental Modelling and Assessment Toolkit

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We present the EAM toolkit for life cycle modelling and impact analysis in environmental assessments. The open source toolkit was specifically designed to support maintainability and verification of models within integrated assessments, and has been used in research and industry. The tool offers features to support complex Life Cycle Assessment, including dynamic and scenario modelling, uncertainty and sensitivity analysis, a flexible domain specific modelling language and a visual editor. In this introduction we present the main features of the toolkit, summarise the high-level components and illustrate its use.

CCS Concepts: • **Human-centered computing → Empirical studies in HCI**; **HCI theory, concepts and models**.

Additional Key Words and Phrases: Environmental sustainability, environmental assessment, LCA

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1 INTRODUCTION

Responsible innovation to support the transition to more sustainable societies requires *among other things* an understanding of environmental impact associated with current and potential future consumption and production of products and services in the economy and society at large. This applies particularly and firstly to engineers and researchers that are conceiving, designing, developing, deploying and operating new and existing systems. Unless quantitative assessment of possible impacts is integrated into these activities, we will not be able to equip the stakeholder communities that use, develop and regulate these systems with the ability to take responsible decisions. Computing is central to support building this quantitative understanding.

The direct measurement (using instruments to collect primary data) of impact from production and consumption processes is almost never practically feasible (e.g. due to scale) or even possible (e.g. of future consumption) and, instead, modelling is usually required to understand the environmental impact of products and services. To support comparability, reproducibility and dependability of results, the main methodology for assessing environmental impacts is the standard for Life Cycle Assessment [4]. The LCA methodology consists of four main steps: I. Goal and Scope setting, II. Inventory Analysis, III. Impact Assessment, and IV. Interpretation. Due to the large number of processes involved in construction of LCA inventories computational modelling tools are commonly supporting LCA - in particular steps II and III. The space of tools commonly used for this purpose includes dedicated (closed or open-source) general

LCA tools (e.g. SimaPro, Gabi, Umberto, openLCA), spreadsheet calculators (Excel) and domain-specific LCA tools [6]. Each come with their own strengths and weaknesses. General LCA tools can be applied to the modelling of most products and services but are often costly — creating a barrier to access for many users and communities. These expert tools also have a steep learning curve and due to general nature use a highly abstracted representation of resource flows that, for large models, can be difficult to verify and validate (V&V). Spreadsheet models on the other hand have a low barrier to access but lack support for important aspects such as uncertainty modelling. As spreadsheet calculators usually use table cell references within formulas, they can also be difficult to V&V. The set of domain specific assessment tools trade these shortcomings in by compromising on size of use.

In response to challenges with performing environmental assessments in the domain of Internet services, our group has developed a custom modelling toolkit, titled Environmental Assessment Modelling — EAM — toolkit. The set of tools is available open source under a BSD-3 license[1].

The toolkit was designed to support sustainable design of digital services, including the flexible representation of complex supply chains. These requirements should be relevant to a wider range of problems and assessment domains. The affordances of the toolkit provide it with some key advantages over alternative modelling solutions, in particular regarding transparency and maintainability of models and inventories and cost. It provides some of the key capabilities of commercial LCA software, such as built-in uncertainty modelling, consistency checks and sensitivity analysis. Additionally, the tool offers some unique modelling features for evaluate scenarios. Together, these features have been highly supportive to our studies and we hope the toolkit will be of benefit to the wider community.

In this text we present the thee components that currently form the EAM toolkit, describe their main features and the advantages they provide for the application area they are designed for.

2 EAM TOOLKIT

The toolkit consists of three main components: i) a "core" calculation engine[1], ii) input data connectors[2], iii) a visual modelling environment (VME)[3]. The tools are implemented in the python programming language but their use does not require programming skills.

The EAM tools offer a few unique features to support the construction of an LCA inventory, which is formed from all relevant environmental "flows" (i.e. material, energy and product outputs) relevant in the life cycle of a product or service. To illustrate the concepts we will use an example away from ICT and refer to a highly simplified representation of an assessment of use of steel during the manufacturing of a car. In LCA environmental flows are quantified (e.g. "use of water, emissions to water or air, etc. during steel manufacturing") and summed up over the entire life cycle. The product or service to be assessed must also be quantified, and is known as the "functional unit" (e.g. "one new car of specific model and make"). The chain(s) of processes that are part of the life cycle form a network of steps with associated flows. The EAM core framework is designed to work on representations of such networks, referred to as EAM models, and sum the flows associated to the network nodes in proportion to the functional unit.

The environmental flows are usually provided by LCA databases relative to some standard unit (e.g. litres of fresh water per kg steel). In order to relate them to the functional unit (e.g. 345kg steel in the car) a conversion takes place. In EAM these conversions are defined through a domain specific language (DSL) that uses a basic formula notation; for example "`polluted_water = total_steel * water_intensity_steel`". The framework operates on "dimensioned"

[1]https://github.com/sust-cs-uob/eam-core
[2]https://github.com/sust-cs-uob/eam-data-tools
[3]https://github.com/sust-cs-uob/eam-vme

variable	electricity_carbon_intensity	electricity_carbon_intensity	world_population
scenario		decarb_1	
type	exp		interp
param			linear
ref value	0.25319	0.15	{"2016-06-01":7000000, "2031-06-01":11000000}
mean growth	-0.1		
initial_value_prop_variation	0.1		0.1
variability growth	0.05		0.05
ref date	01/07/2020		01/07/2019
unit	kg/kWh		
source	DEFRA UK 2020 Emissions factor including for Scope 2 and T&D losses (see above)		

Table 1. Example of variable properties defined with a data table. For layout reasons the table was transposed. In this example three variables are defined. They were chosen for illustrative purposes. Their actual values are of no significance. The variable *electricity_carbon_intensity* has an annual compound reduction of 10%. The reference value is 0.25319 kg/kWh (to represent $kgCO_2e/kWh$) for the 01.07.2020. At the reference date the uncertainty is 10%. This uncertainty increases by 5% per year. Besides the default value, the variable also has is a scenario value defined for the scenario *decarb_1*, where the reference value is set to 0.15 kg/kWh, while all other properties are equal. The variable *world_population* is defined with a reference value of 7,000,000 for 1.6.2016 that linearly grows 11,000,000 by 1.6.2031.

variables with units and validates that units are consistent within formulas and nodes. Variable values can propagate along the connections between processes (e.g. 345kg steel output from the smelting process is input to the forming of metal sheets).

The parameter values for the formula variables and their units can be defined together with the formulas within the DSL. However, a much more flexible approach offered by EAM is to define these in a separate table. The separation of model structure and parameterisation allows for more flexible evaluation of scenarios. Additionally, the extra space in a table allows to define additional properties to the parameters, for example uncertainty/variability, age or meta information such as data sources and notes see Table 1. Variability is defined either as probability distribution functions or as entire population to sample from. Input value tables can be read from CSV or from spreadsheets application formats, including Excel and Google Sheets via that EAM Data Tools. Future work includes the development of adapters to LCA databases such as ecoSpold for ecoInvent [8].

Following the construction of a LCA inventory in form of a model EAM carries out the Analysis step (II) by computing and summing all relevant flows and applying impact categorisation factors, such as Global Warming Potential, measured in $kgCO_2e$. Frequently, assessments are required to consider additional factors such as uncertainty or change over time during the LCA interpretation phase (IV). EAM supports the modeller in a few different ways. EAM can represent parameter variability in model parameters and the core library applies Monte Carlo simulation to evaluate this variability. Secondly, EAM explicitly represents time in its calculations. This allows to evaluate changes to product systems over time. More specifically, EAM can evaluate non-recursive, dynamic models [1]. Models are directed acyclic graphs, thus do not currently allow recycling loops. Change over time in model parameters can be defined through growth functions (linear, exponential) or explicitly through step functions. Thirdly, assessment parameter values frequently vary within the model along other dimensions than time, for example by geographical region or some other population dimension (e.g. households vs corporate users). EAM supports the definition of separate "groups" for a variable to distinguish between additional dimensions. Taken together, EAM operates internally on hypercubes of variable values with associated physical units, variability distributions and temporal change. To further support the interpretation of the results, EAM provides the output of the calculation as numeric values and in form of a variety of diagrams, including graphs and process trees. And finally, the most significant variables in the life cycle can be identified through sensitivity analysis — currently with One-at-a-time sensitivity analysis [3]. While EAM models can be composed programmatically through interaction with the python runtime, for example in an interactive environment such as jupyter notebook, for the majority of use cases it is preferable to provide EAM with fully declared models. EAM can read and store assessment models as YAML files, YAML is a widely used, human-readable, data-serialization or 'markup' language. The use of plain YAML files has the benefit that popular version control systems, such as Git, can be fully leveraged for benefits such as versioning of models. While the YAML format is very flexible and easy to parse (see an example in listing 1) , the EAM VME also provides a visual editor to create models with low barriers to entry (see figure 1). It uses a dialog driven click and drag interface to lay out networks of processes and to edit their properties. The visual editor is currently in a beta state.

The EAM toolkit has been successfully used for quantitative modelling in previous research, e.g. to evaluate sustainable interaction design of digital services[5] and assess the environmental impact of television platforms [7]. The EAM core library is also used in the DIMPACT tool [2]. We hope the wider community finds these tools equally useful. Interested readers can follow step-by-step instructions to the installation of the toolkit and a simple model on the toolkit GitHub page.

```
Processes:
  - name: Laptop
    exportVariables:
      - data_volume_laptop
    formula: |
      energy = power_laptop * time_laptop;
      data_volume_laptop = time_laptop * bitrate_lapto
      carbon = energy * carbon_intensity;
    link_to:
      - Network
  - name: Network
    ...
```

Listing 1. Snippet of section "Processes" in EAM model yaml. A single process "Laptop" is shown, including its formula that calculates energy and carbon flows. An `exportVariable` is used to make a variable available in a downstream process — here the "Network" process.

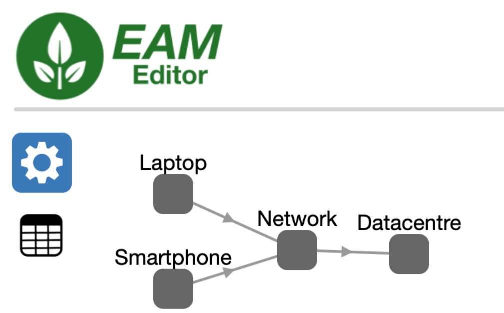

Fig. 1. Screenshot of the EAM VME showing a simple model of a digital service.

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