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FROM DETAILED LCA TO SIMPLIFIED MODEL: AN ORIENTED DECISION MAKERS APPROACH TO ASSESS ENERGY PATHWAYS

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ABSTRACT

Literature reviews of energy pathways have shown a large variability of the environmental impacts over their systems. This leads decision/policy makers to sometimes consider LCA as inconclusive. We developed a methodology to assess environmental impacts of energy pathways through a simplified model: a parametric model elaborated with key parameters explaining most of the pathway variability. It is derived from the definition of a reference model enabling to calculate environmental impacts of a large sample of representative systems of energy pathways. Identification of key parameters is done using Global Sensitivity Analysis and Sobol indices. Illustration of such approach is done by defining a simplified model for assessing the GHG performance of photovoltaic electricity produced with Cadmium Telluride modules in France.

INTRODUCTION

Energy pathways can be assessed through literature reviews accounting for various specific systems. These studies highlight a wide range of possible environmental impacts (IPCC, 2011) and lead decision and policy makers to sometimes consider LCA as inconclusive (Brandão, Heath, & Cooper, 2012). For example, the photovoltaic electricity pathway is made of various systems encompassing a large technological and geographical heterogeneity (Kim, Fthenakis, Choi, & Turney, 2012) leading to a wide range of impacts. Detailed LCA of a system within an energy pathway being site and technology-specific, is only representative of single situations and cannot be representative at large for any energy pathway. To get a comprehensive explicit analysis of the environmental performance profile of an energy pathway, there is a need for a new type of models considering the technical, temporal and geographical heterogeneity of the systems sample composing this pathway.

We developed a methodology to generate such type of models, called simplified models. It enables encompassing energy pathway's variability by analysing their impacts over a large sample of representative systems using Monte-Carlo simulations. Applying Global Sensitivity Analysis approach (Saltelli, 2004), we then generate simplified models based on key parameters explaining most of the variance of the studied pathway. We now apply this methodology to define a simplified model estimating the GHG performances for photovoltaic (PV) electricity produced with Cadmium Telluride (CdTe) modules in France.

METHODS

We developed a methodological framework in five steps to assess an energy pathway and to generate its related simplified model (Padey, Girard, le Boulch, & Blanc, 2013). As a first step, the level of generalization is defined, i.e, what variability is accounted for, by specifying the geographical, temporal and technological coverage of the studied pathway.

We then need to define an explicit reference model as a second step. Such model is defined according to the specifications from step 1. It relies on the setting of a parameterized model such as the approach developed by Zimmermann (2012) built with independent variables, and on the characterization of its parameters through their interval and probability distributions, being as well compliant with the specifications from step 1. Based on the parameters characterization, a systems sample representing the energy pathway is generated by Monte Carlo simulations, to create its environmental profile.

To estimate the share of variance due to each parameter and their combinations, we followed a Global Sensitivity Analysis (GSA) and derived the related Sobol indices (Sobol, 2001). This third step enables ranking parameters influence and identifying which one are keys, i.e. explaining most of the environmental impact variance.

In step 4, the sample scattered plot is reorganized as a function of the key parameters and a general regression approach is used to calculate the median parametric equation. It enables estimating the impacts of various systems as a function of the key parameters, being thus the simplified model. In addition of the simplified model, on the scattered plot, non key parameters contributions are represented with the extreme boundaries and the, 1st and 3rd quartile of the sample.

Finally, in step 5 we compare the results of the simplified model with results from literature to assess the validity of the simplified model estimates.

RESULTS

We applied this methodology to define a simplified model estimating the GHG performances (in g of CO_2 eq/kWh) for a specific energy pathway: PV electricity produced with 3kWp CdTe installations in France.

The process chain analysis for PV module manufacture has been kept from the ecoinvent database (Hischier et al., 2009) to define the parameterized model. However, module area is parameterized according to the module efficiency as well as the electricity mix for manufacturing at the location of the module production. Variability sources are identified by seven uncorrelated parameters (Figure 1).

Parameter	Description	Characterization
Installation type	Selection of the architecture, Discrete choice between 2 options : Integrated or mounted	Expert judgment, 50% mounted, 50% integrated
Irradiation (Irr)	Annual irradiation received per m^2 in [kWh./ m^2.y]	Based on information provided by a collaborative website BDPV, (2013)
Performance Ratio (PR)	Takes into account: shadowing losses, connection losses, inverters losses in [%]	Based on works from Leloux, Narvarte, & Trebosc (2011)
Module Efficiency	Percentage of solar energy to which the module is exposed and converted into electrical energy in [%]	Data from the database Posharp, (2013)
Lifetime (LT)	Considers the entire period when the system is installed on the roof in years [y]	[20;30], Truncated normal law centered on 25 years, SD=2 , expert

Module Loss	Considers the loss of system efficiency during the lifetime compared to initial efficiency in [%]	[0.5; 1] uniform distribution; expert judgment
Country of module production	Country where the module is built influences the electricity mix required for the manufacturing	Origin of production from Dominguez-Ramos, Held, Aldaco (2010); electricity mix composition from IEA, (2013)

Figure 1. Explicit parameters of the reference model: description and characterization

25’000 Monte Carlo simulations have been sampled and GHG performances have been estimated for these scenarios creating the GHG performance profile of the energy pathway. Key parameters have been identified according to their Sobol indices values (Figure 2).

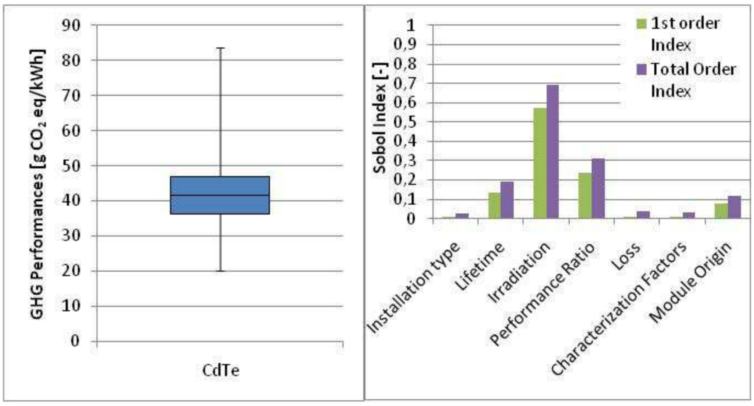

Figure 2. Boxplot of the PV electricity GHG performances (left), Sobol indices for each parameter (right).

The irradiation, performance ratio and lifetime are found to be the three most influencing parameters (79% of the overall variance explained). Thereby we propose the following parameterized equation estimating the GHG performance of the CdTe PV electricity pathway:

$$\text{GHG performances CdTe} = \frac{919651+9571.\text{LT}}{\text{LT.PR.Irr}} \quad \text{with } R^2 = 0.79$$

The simplified model is expressed as a function of the product of the three main parameters, as well as a validity assessment on Figure 3.

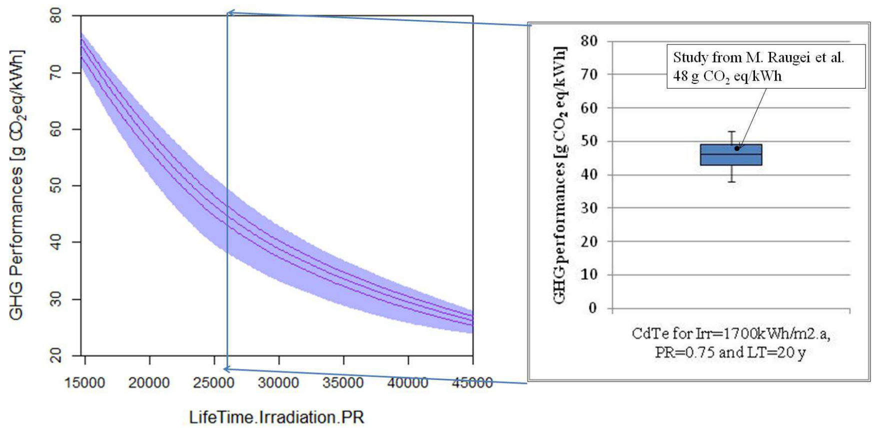

Figure 3. Simplified model (left) and literature comparison with a specific CdTe system (right)

DISCUSSION

Using this parametric equation enables estimating the electricity GHG performances of 3kWp CdTe PV systems installed in France only knowing three key parameters.

The reference model (step 2) is complex to define as it requires the collection of a large number of data; it also requires identifying independent parameters, in order to apportion the overall environmental performances variability to parameters variability. Whenever new data become available, a new reference model is to be redefined.

The number of key parameters selection is a choice, according to the level of simplification decided; three, two or even one parameter can be selected. The less parameters are chosen, the simpler is the model, but with potentially less accurate estimates.

CONCLUSIONS

Simplified models, according to this approach, have two significant outcomes for decision makers: the environmental impact profile of an energy pathway is explicitly characterized while access to impacts of systems is easily provided only knowing a restricted but key number of information. However, setting such approach requires the definition of an explicit reference model and access to a large amount of data that are complex to get today. Development of technical databases is fundamental to provide efficient policy support tools.

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