Understanding LCA results variability: developing global sensitivity analysis with Sobol indices: *A first application to GHG from Photovoltaic systems*

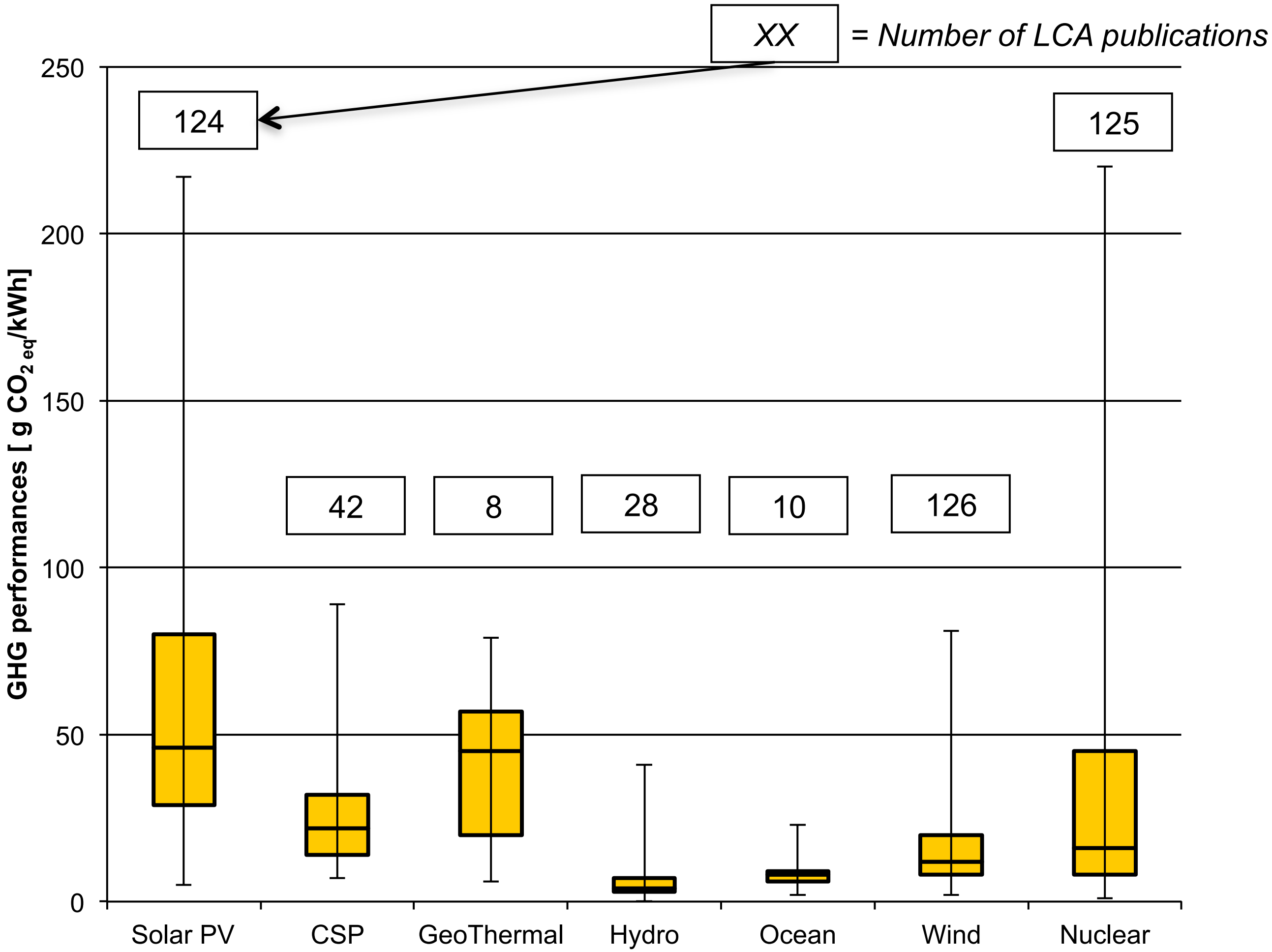
LCA & Construction

Session : *LCI data : validation, aggregation, uncertainties*

Pierryves Padey, Didier Beloin-Saint-Pierre, Robin Girard, Denis Le Boulch, Isabelle Blanc*

Mines ParisTech / EDF – R&D

Problematic: GHG performance for electricity generation highly variable



➔Policy-makers misunderstanding

➔Need for **a better understanding of the variability** (for futur electricity mix development)

[1] IPCC, Special Report on Renewable Energy Sources and Climate Change Mitigation. United Kingdom and New York, NY, USA: Cambridge University Press, 2011.

Issues on variability

- High variability of the LCA results for energy pathways
  - Need for a better knowledge of its origin (technology, methodology, geographic)

- Sensitivity analysis are incomplete
  - One Factor at a Time (OAT) approach : variation of one factor the other remained constant
  - Best / Worst case scenarios : parameters set at a minimum and a maximum value
  - Local Sensitivity Analysis: parameters' variations around the nominal value

  ➔ *Parameters interval of variation and probability distribution not considered*

➔Can we explain the variability of LCA results for an energy pathway?

➔How to fully consider the variability sources?

➔Can we rank the parameter influences ?

Tool to analyze the variability

- Solution: Global Sensitivity Analysis and Sobol Indices
  - Parameters variability fully integrated (interval and distribution)
  - Variability of all parameter assessed simultaneously
  - Parameters joint influences considered
  - Ranking of the parameter influence

- Total variance decomposed in sum of variance due to each parameter and their combinations

$$Var[Y] = \sum_{i=1}^{n} V_i\,(Y) + \sum_{i<j} V_{ij}\,(Y) + \sum_{i<j<k} V_{ijk}\,(Y) + \cdots + V_{1,2\ldots d}\,(Y)$$

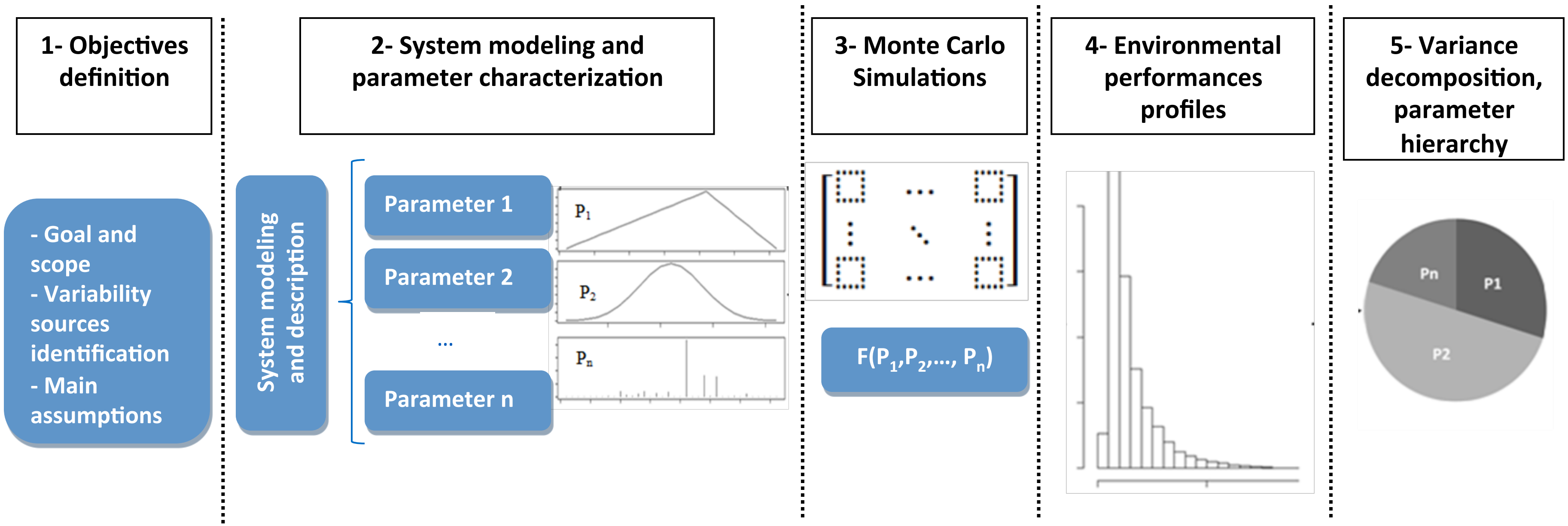
  - Where

$$V_i(Y) = Var[E(Y|X_i)]\;;\; V_{ij}(Y) = Var\left[E\left(Y\middle|X_iX_j\right)\right] - V_i(Y) - V_j(Y)$$

  - Sobol Index : Ratio between the variance due to one parameter (or a combination) and the total variance

$$S_i = \frac{Var[E(Y|X_i)]}{Var(Y)} = \frac{V_i(Y)}{Var(Y)} \qquad S_{ij} = \frac{V_{ij}(Y)}{Var(Y)} \qquad S_{ijk} = \frac{V_{ijk}(Y)}{Var(Y)}$$

Methodology

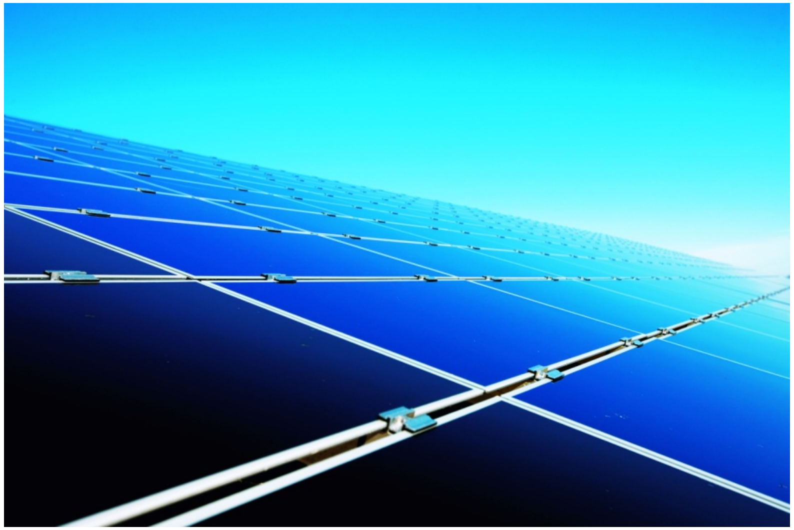


- Objectives (step 1) : Set which variability is accounted for
  ➔ *Key*

- System modeling and parameter characterization (step 2)
  ➔ *Require transparency and interpretation*

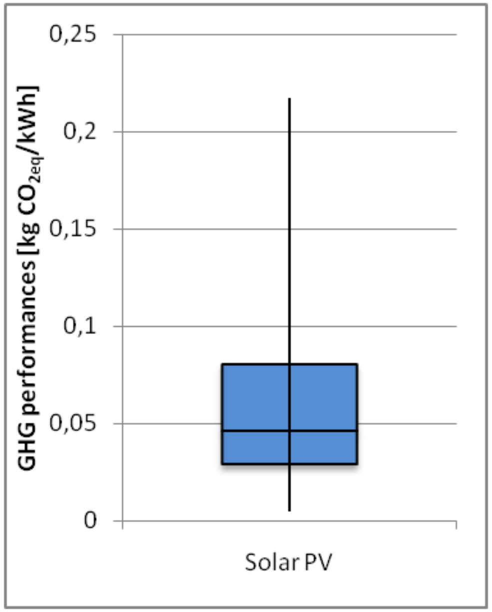
APPLICATION OF THE GLOBAL SENSITIVITY ANALYSIS (GSA)

To building integrated PV systems in France



LCA of photovoltaic: variability origins

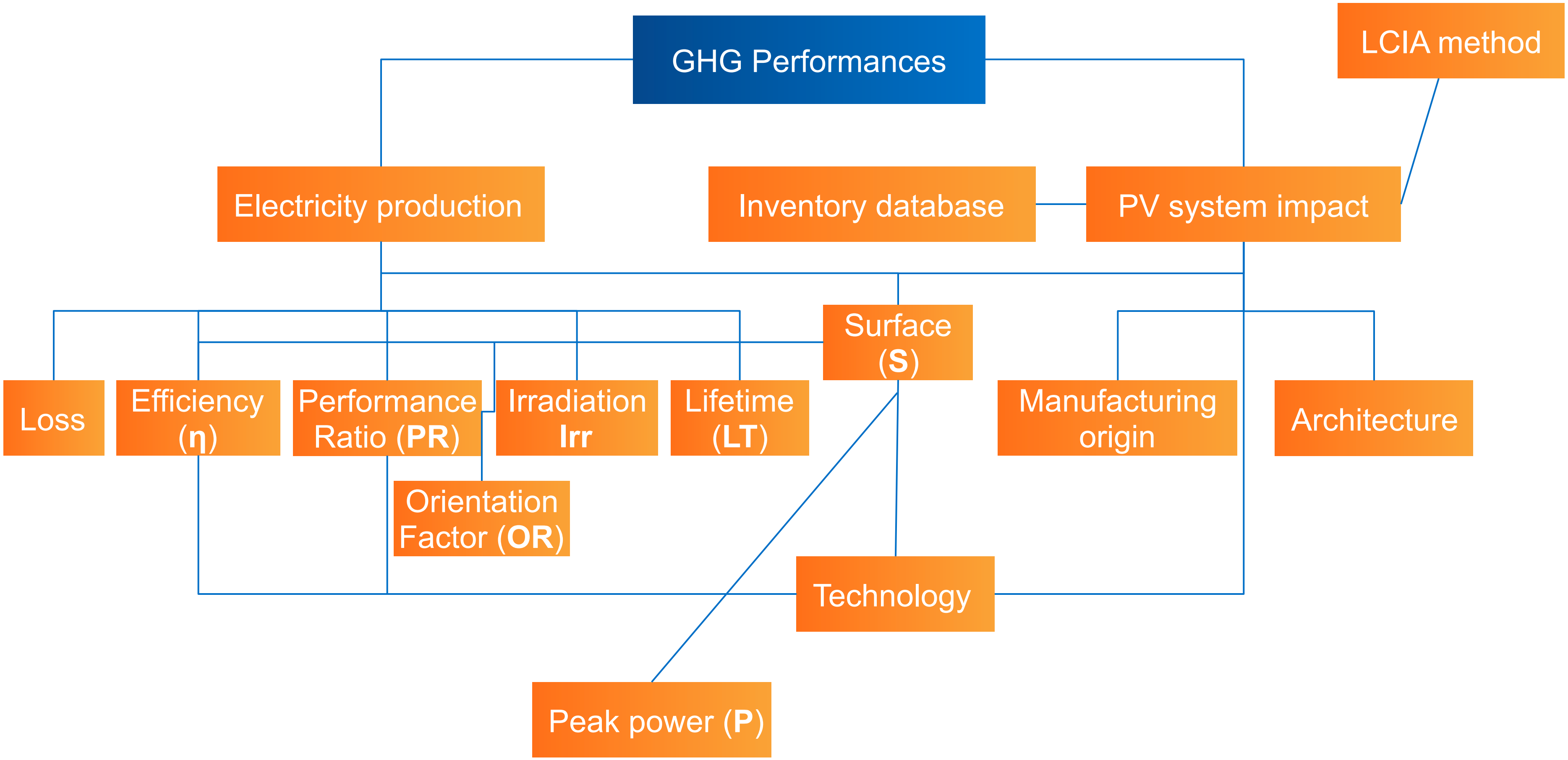
- Induced by:
  - System modeling hypothesis
  - System boundaries
  - The technology (Single / Multi, integrated/mounted, efficiency…)
  - Manufacturing origin
  - Electricity production (location…)
  - Database
  - LCIA characterization factors



Source: [1]

	GHG performances [kg CO_2 eq/kWh]
Minimum	0.005
1st quartile	0.029
Median	0.046
3rd quartile	0.080
Maximum	0.217

System modeling considering variability sources



$$PV\ GHG\ performances = \frac{Impact_{PV\ System}}{Electricity_{production}} = \frac{Impact_{PV\ System}}{\eta . OR . PR . S . Irr . LT . Loss}$$

MINES ParisTech

eDF

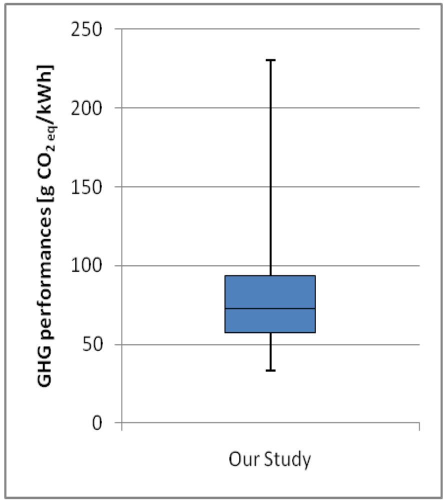
Parameters characterization – French case

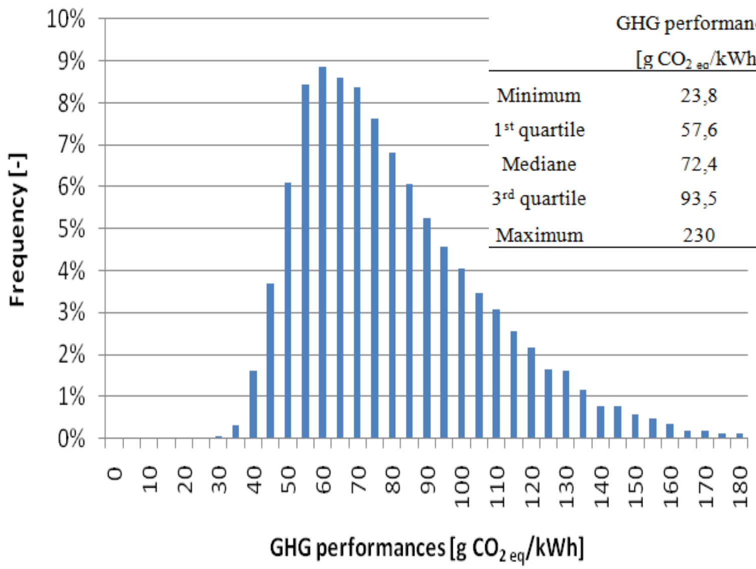
	Parameters	Characterization
[1]	**Peak Power [kW]**	Study on residential: fixed at 3kWp
[2]	**System selection** [-]	2 types of technologies: single and multi-silicon 2 types of installations structure: mounted and integrated Equiprobability over these 4 technical choices
[3]	**System Impacts [kg CO_2 eq]**	Module impacts (for both technologies and installation structures) from ecoinvent V2.2 LCI uncertainty considered by performing Monte Carlo simulation with the Pedigree matrix approach
[4]	**Irradiation [kWh/m^2]**	Annual irradiation between 900 to 2200 kWh/m² Uniform distribution
[5]	**Lifetime [years]**	Lifetime between 20 and 30 years (literature observations) Truncated normal law centered on 25 years with SD=2
[6]	**Efficiency [%]**	Efficiency ranges and distributions estimated according to IEA PVPS work Variability due to the system selection and the efficiency variability for a same technology addressed
[7]	**OR [-]**	Orientation factor range between 0, 75 to 1. Represents installation from optimized to fully perpendicular or fully horizontal Represents also installation directed in the western or eastern direction
[8]	**PR [-]**	Performance ratio range and distribution estimated according to IEA PVPS work ranging from 0.65 to 0.90
[9]	**Surface [m^2]**	Systems' surfaces calculated as a function of system efficiency to maintain the peak power constant
[10]	**Loss [%]**	Loss factor of 0.5 to1% each year in production compared to year n-1

MINES ParisTech eDF

Monte Carlo results - GHG performances distribution

20'000 Monte Carlo simulations





	GHG performances [g $CO_{2\,eq}$/kWh]
Minimum	23,8
1st quartile	57,6
Mediane	72,4
3rd quartile	93,5
Maximum	230

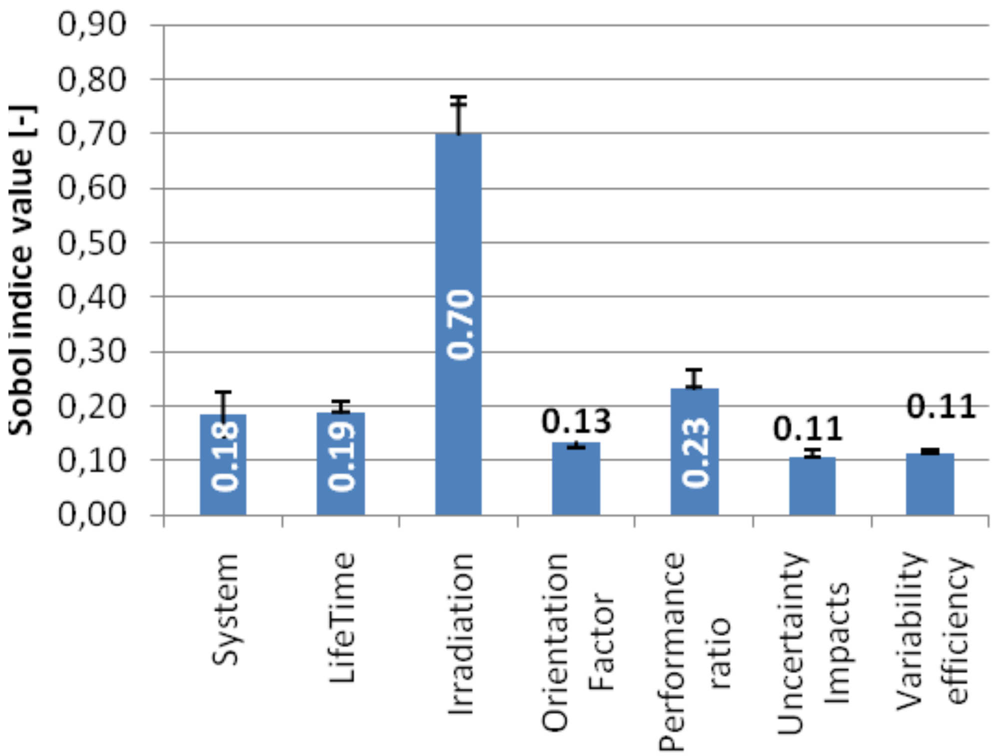
- Random combination of the 9 parameters

- Monte Carlo simulations give information of the output variability
- **- GHG performances between 23.8 to 230 g CO_{2eq}/kWh**
- **- Mostly between 45 and 140 g CO_{2eq}/kWh**

➔ But It does not link the environmental outcome variability to the parameters variabilities:
- Need to assess more in details the obtained results

MINES ParisTech
EDF

GSA results – Identification of the parameters' influences



- Large influence of the irradiation, linked to the electricity production

- Other influent parameters : the performance ratio

➔ According to the defined model, it is necessary to assess in detail the electricity production

Conclusion

- The GSA application enables a better (and more complete) understanding of the LCA result variability
  - Consider interval and probability distributions for all parameters
- Quantitative assessment
  - Main variability sources identified
- Give information about the optimization priority (help for policy makers)
  - Highlight the critical parameters of a system, to be strictly specified
- Issues / Constraints
  - Variability assessment highly depends on the model reference used
    - Module’s origin to be considered, which scenarios?
  - Large amount of data to be collected

MINES ParisTech

EDF

Contact: Pierryves Padey
Mines ParisTech – Center for Energy and Processes
EDF – R&D - Eco-Efficiency and Industrial Process
Phone: +33 1.60.73.62.55
Email: pierryves.padey@mines-paristech.fr

THANK YOU FOR YOUR ATTENTION

DO YOU HAVE ANY QUESTIONS?