Life cycle assessment of the different energies: methodology for contributing to a justified multicriteria energy transition – The French case

Didier Hartmann, Maxime Teixeira*
French Alternative Energies and Atomic Energy Commission, CEA Marcoule, ISEC/DMRC/STDC, University of Montpellier, BP 17171, 30207 Bagnols-sur-Cèze Cedex, France
(*): corresponding author: didier.hartmann@cea.fr

Objectives:

- Classify the different energies in terms of environmental impact, production cost and social acceptance and propose a rule for a multicriteria assessment depending on stakeholders' viewpoint
- Give a tool for policy makers about the energy transition; application to the French case with a lot of energy choices.

1. COMPARISON OF ENERGIES

Fig 1 shows the relative contribution of different energies to an impact category, each producing 1 kWh of electricity and normalized to 100%. The IMPACT2002+ method was chosen as an example.

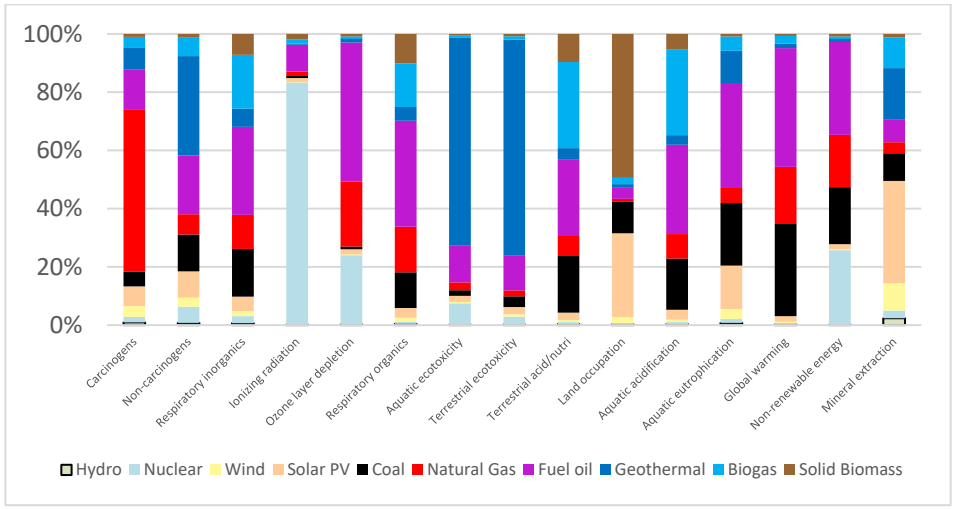

Fig. 1: Comparison of impact for 1 kWh produced with different technologies (IMPACT 2002+ Midpoints)

Energy	Human Health	Ecosystem Quality	Climate Change
Hydro	1	1	1
Wind	2	2	3
Nuclear	3	4	2
Solar PV	4	6	6
Solid Biomass	5	7	4
Geothermal	6	10	5
Natural Gas	7	3	8
Coal	8	8	9
Biogas	9	5	7
Fuel oil	10	9	10

Table 1: Ranking of the energies using IMPACT 2002+ endpoints for 1 kWh of electricity produced

2. SCENARIO SELECTION

Scenario	Year	Nuclear	Renewables	Fossil	Storage	Intermittent renewables
	2018	73.0%	19.7%	7.3%	1.0%	7.1%
A	2035	50.0%	50.0%	0.0%	0.9%	37.4%
	2050	43.0%	57.0%	0.0%	3.2%	45.5%
B	2035	50.0%	50.0%	0.0%	2.0%	37.4%
	2050	49.6%	50.4%	0.0%	2.0%	37.1%
C	2035	49.8%	44.2%	6.0%	1.7%	30.6%
	2050	0.0%	94.3%	5.7%	3.4%	79.5%
D	2035	59.0%	35.7%	5.4%	0.9%	23.5%
	2050	60.5%	39.5%	0.0%	0.7%	28.8%

Table 2: Share of the different energies in the electric production mix for each scenario

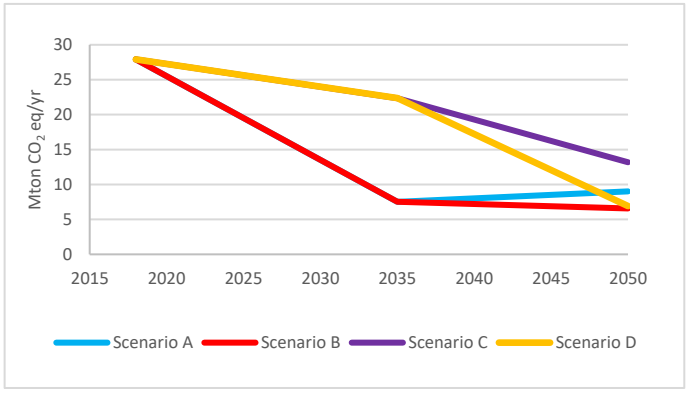

Fig. 2: Global warming damage for each transition scenario (IMPACT 2002+)

3. MULTICRITERIA ASSESSMENT

3.1. General considerations and assumptions

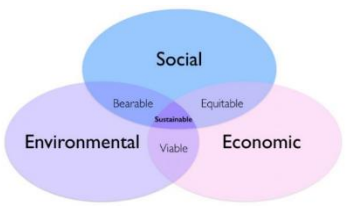

Fig. 3: The 3 pillars of sustainable development

Ecosystem quality ranking (1-10)	40%
Abiotic depletion (EPS 2015dx) ranking (1-10)	20%
Climate change ranking (1-10)	40%

Table 4: Weighting factors used to determine the "Environmental score"

Human health ranking (1-10)	50%
Number of direct jobs / kWh (1-10)	30%
Perceived risk-consequence in the case of major accident (1-5)	20%

Table 3: Weighting factors used to determine the "Social score"

Criterion	Economic	Environmental	Social
Industrial and investor approach	70%	20%	10%
Authorities approach	30%	40%	30%
Population approach	10%	50%	40%

Table 5: Choice of weighting criteria for decision support

3.2. Economic score

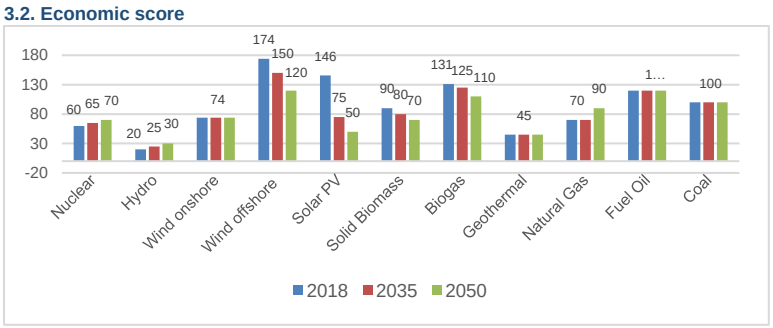

Fig. 4: Projections of overall production cost of energies (€/MWh)

3.3. Overall scores of the energies **(the lower the better)**

Viewpoint	*Year*	*Solid Biomass*	*Wind*	*Geothermal*	*Solar PV*	*Hydro*	*Biogas*	*Nuclear*	*Natural Gas*	*Coal*	*Fuel oil*
Investors	*2018*	*5.29*	*4.48*	*3.50*	*9.17*	*1.38*	*8.40*	*3.34*	*4.23*	*7.12*	*7.96*
	2035	*5.29*	*5.88*	*3.50*	*5.67*	*1.38*	*9.10*	*3.34*	*4.23*	*7.82*	*8.66*
	2050	*3.89*	*6.58*	*3.50*	*4.27*	*1.38*	*8.40*	*4.04*	*5.63*	*7.12*	*9.36*
Authorities	*2018*	*4.27*	*3.79*	*5.23*	*7.78*	*2.14*	*7.41*	*3.89*	*4.77*	*7.28*	*8.08*
	2035	*4.27*	*4.39*	*5.23*	*6.28*	*2.14*	*7.71*	*3.89*	*4.77*	*7.58*	*8.38*
	2050	*3.67*	*4.69*	*5.23*	*5.68*	*2.14*	*7.41*	*4.19*	*5.37*	*7.28*	*8.68*
Population	*2018*	*3.77*	*3.44*	*6.09*	*7.09*	*2.52*	*6.91*	*4.17*	*5.04*	*7.37*	*8.14*
	2035	*3.77*	*3.64*	*6.09*	*6.59*	*2.52*	*7.01*	*4.17*	*5.04*	*7.47*	*8.24*
	2050	*3.57*	*3.74*	*6.09*	*6.39*	*2.52*	*6.91*	*4.27*	*5.24*	*7.37*	*8.34*

Table 6: Multicriterion scores of electricity sources depending on 3 different approaches (ReCiPe)

4. MULTICRITERIA SCENARIO CLASSIFICATION WITH EXTENDED SCORES

We decided to take into account the differences of magnitude in scores for the energies, normalising them through a ratio with respect to the best one. This allows a better separation of the energies compared to giving a uniform score from 1 to 10.

	Score/ Ranking	Solid Biomass	Wind	Geother-mal	PV	Hydro	Bio-gas	Nuclear	Natural Gas	Coal	Fuel Oil
Social	Score	2.50	2.94	5.68	5.96	5.96	10.5	5.75	21.1	35.9	56.5
	Ranking	1	2	3	5	6	7	4	8	9	10
Environ-mental	Score	17.4	4.11	7.45	21.6	1	26.3	3.12	38.1	75.4	91.7
	Ranking	5	3	4	6	1	7	2	8	9	10
Econo-mic	2018 score	4.50	3.70	2.25	7.29	1	6.55	2.99	3.50	5.00	6.00
	2035 score	3.20	3.72	1.80	3.00	1	5.00	2.60	2.80	4.00	4.80
	2050 score	2.33	3.62	1.50	1.67	1	3.67	2.33	3.00	3.33	4.00

Table 7: Detailed scores for electricity sources with extended scores methodology (ReCiPe method)

Viewpoint	Investors		Authorities		Population		Mean value		Final ranking	
Scenario	2035	2050	2035	2050	2035	2050	2035	2050	2035	2050
A	3.46	3.42	4.40	4.52	4.85	5.07	4.24	4.34	1	3
B	3.46	3.29	4.40	4.37	4.85	4.90	4.24	4.19	1	1
C	3.88	4.52	5.40	6.49	6.15	7.48	5.14	6.16	4	4
D	3.76	3.25	5.22	4.44	5.94	5.04	4.97	4.24	3	2

Table 8: Multicriteria scores for the scenarios and rankings

5. COMPARISON WITH THE FINAL ENERGY CONSUMPTION

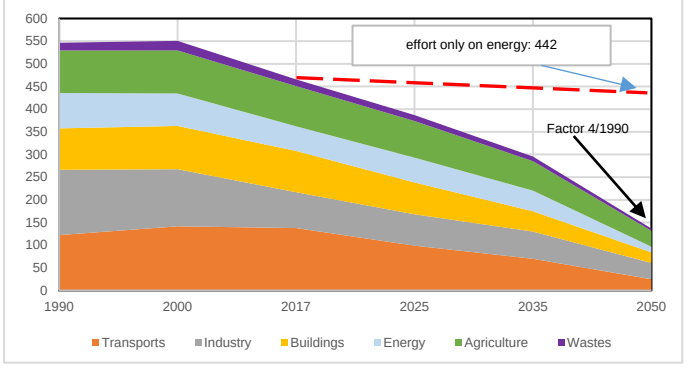

Fig 5: Past and predicted greenhouse gas emissions per sector in France (Mton CO2 eq/yr)

6. CONCLUSIONS AND POLICY IMPLICATIONS

Main results

- Start from LCA results of energies: 15 impact categories and endpoint approach to limit the number of parameters → comparison and ranking of the different energies used for the production of electricity
- Multicriteria assessment including economic and social indicators (for economic, dynamic approach of the overall production cost)
- Different stakeholders' viewpoints
- Final result: multicriteria ranking of energies
- Application to the energy transition with 4 different scenarios
- A worksheet has been set up to allow a wide choice of tuneable parameters, which is important to match different needs.

Prospects

- Further parameters to be developed:
  - For social issues, other relevant parameters could be added
  - For the environmental part, the predictable technologies and their inventories should be assessed with associated uncertainties for the future
  - Scores to be evaluated by a broader panel of citizens
- This study can be broadened to other countries, with possibly very different energy mixes.

LCM 2021