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Waste to Methanol process

Eco sustainability assessment from a life cycle perspective of a potential circular end-of-life process

Alessio Castagnoli, Ahmed Salem, Isabella Pecorini, Renato Iannelli, Umberto Desideri

Dott. Alessio Castagnoli
PhD Student
DESTEC - Dipartimento di Ingegneria dell'Energia dei Sistemi, del Territorio e delle Costruzioni
LISAP - Laboratorio di Ingegneria Sanitaria Ambientale dell'Università di Pisa
e-mail: alessio.castagnoli@phd.unipi.it

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Summary

I Research Background & Motivation

- 3.347.529 t of secondary waste produced in the Tuscany region (ARRR, 2021);
- About 300.000 t energetic valuable in the Alia multiutility competence territory. About 2/3 of these are actually landfilled (Alia, 2021);
- Collaboration between LISAP and Desideri's research groups to assess these wastes' potential by a Life Cycle Approach.

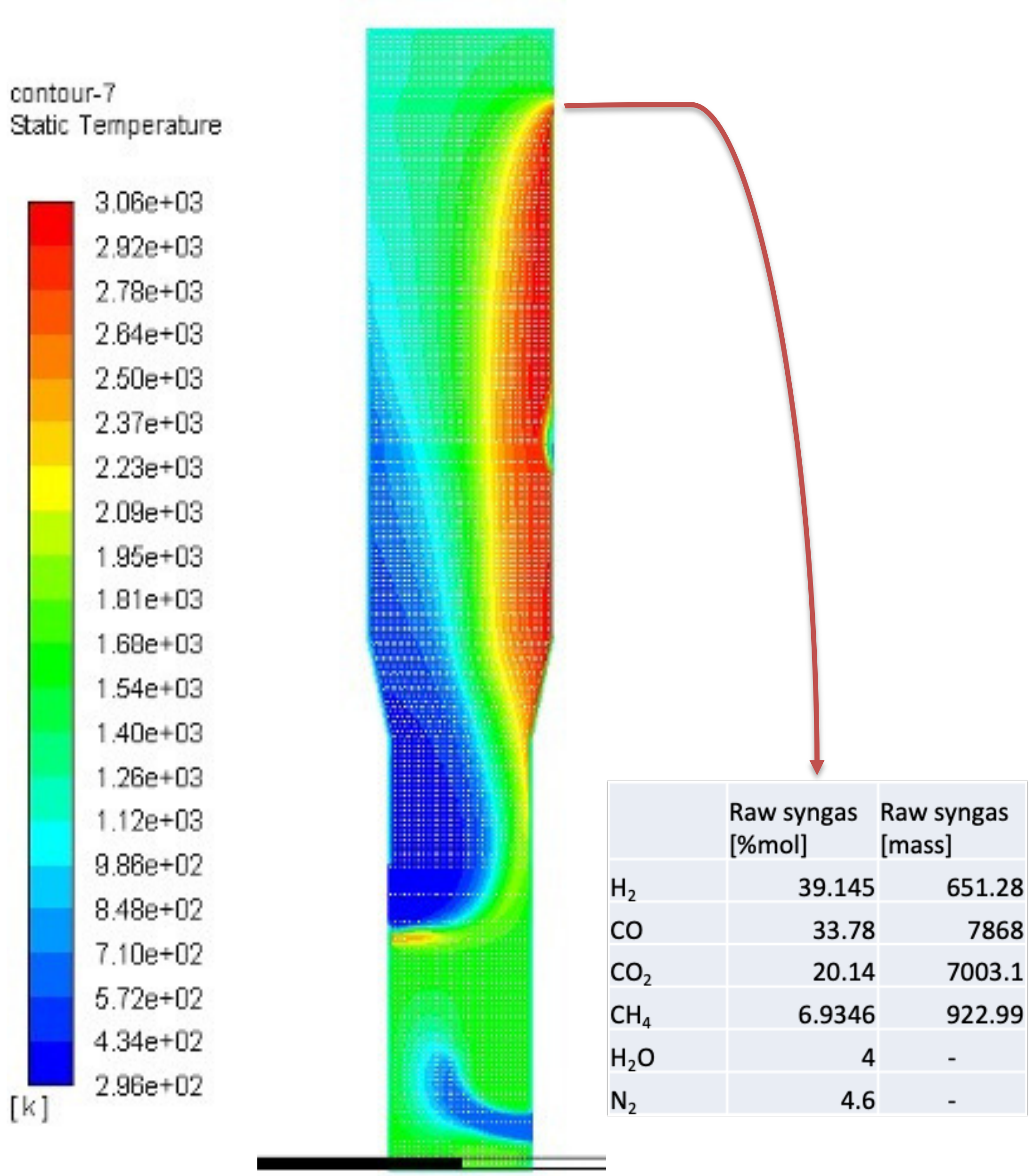
Alia territory	**2018 [t]**	**2019 [t]**	**2020 [t]**
Recycling	487.276	551.743	518.409
Waste to Energy	74.540	87.453	99.646
Landfill	327.579	252.662	216.729
Total	889.395	891.858	834.784

I Research Background & Motivation

Waste to methanol process

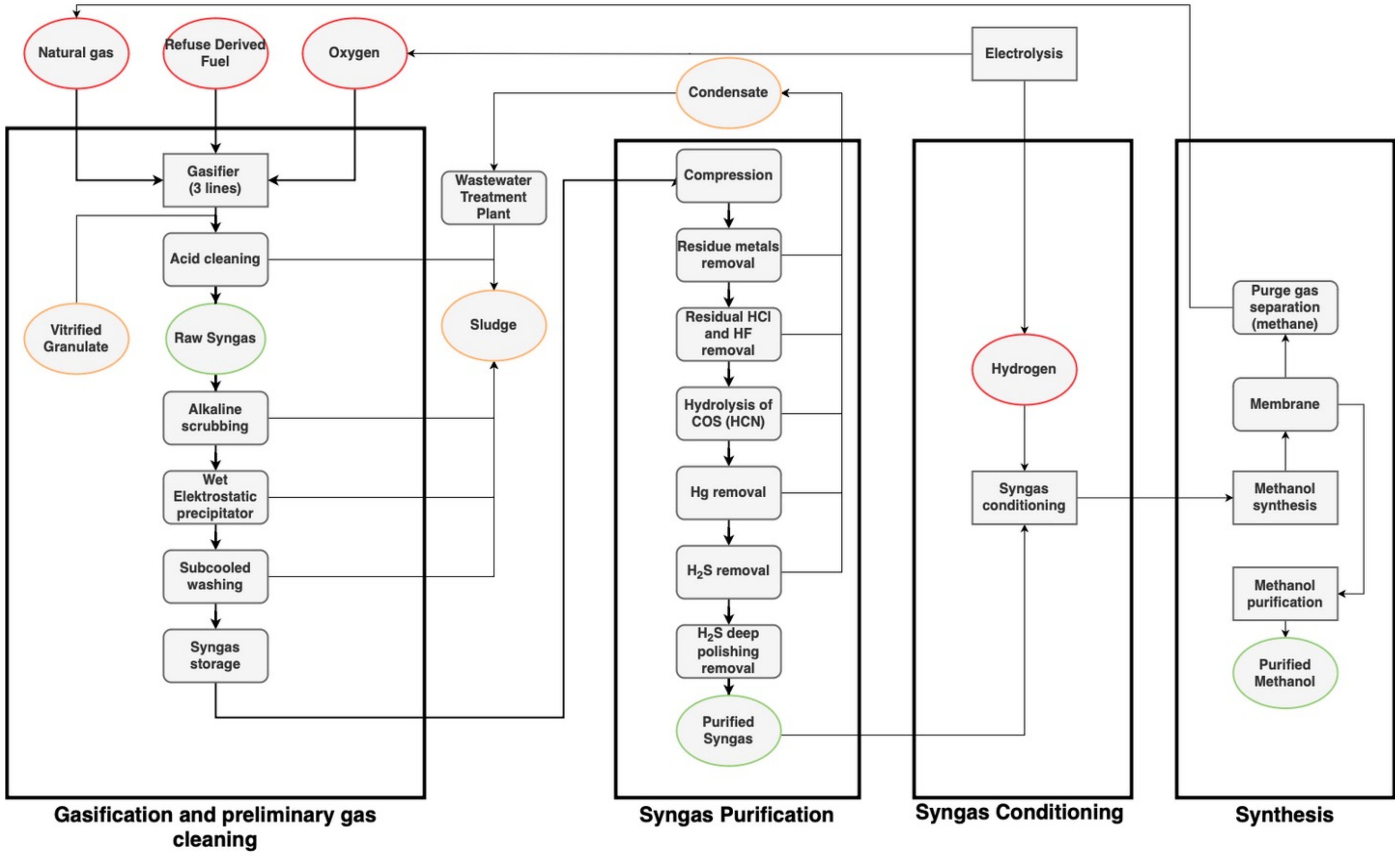
Stoichiometric reactions for methanol production:

$$CO+2H_2 \rightleftarrows CH_3OH$$
$$CO_2+3H_2 \rightleftarrows CH_3OH+H_2O$$
$$CO_2+H_2 \rightleftarrows CO+H_2O$$



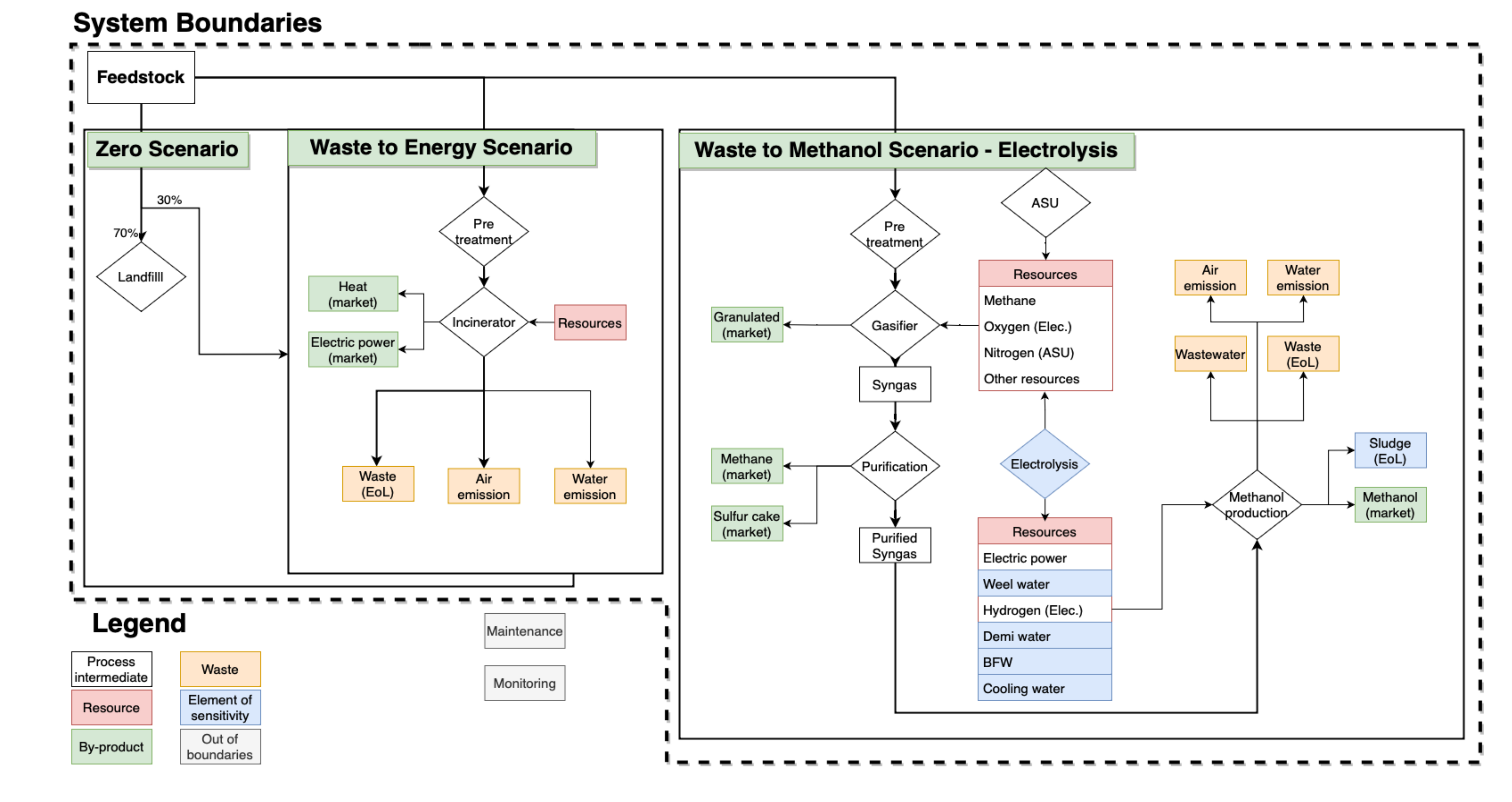
	Raw syngas [%mol]	Raw syngas [mass]
H_2	39.145	651.28
CO	33.78	7868
CO_2	20.14	7003.1
CH_4	6.9346	922.99
H_2O	4	-
N_2	4.6	-

Temperature distribution in the gasifier



Flow-diagram of waste to methanol process with addition of Green Hydrogen

II Materials and Methods



Systems boundaries of the three scenarios analyzed: Zero scenario, Waste to Energy scenario and Waste to Methanol scenario

II Materials and Methods

Zero Scenario

- 70% of waste landfilled and 30% to Waste to Energy;
- Waste to Energy process like Waste to Energy Scenario.

Waste to Energy

- Waste pre-treatment for RDF production modelled through plant data;
- Biogenic and fossil emissions of CO_2 calculated according to GHG Protocol and literature (Christensen et al, 2009);
- Energy and thermal recover by literature (Turconi et al, 2011);
- Emissions and Background data by Ecoinvent 3.8.

Waste to Methanol - Electrolysis

- Waste pre-treatment for RDF production modelled through plant data;
- Gasification process modelled by Matlab;
- Resource consumption calculated according to literature (Borgogna et al, 2021);
- Electrolysis energy consumption calculated according to literature (Carmo et al., 2013; Tenhumberg et al, 2020);
- Emissions and Background data by Ecoinvent 3.8.

II Materials and Methods

Software used: SimaPro 9.3;
Database used: Ecoinvent 3.8;
Method adopted: ReCiPe 2016 Midpoint (H) CV1.07/World (2010).

	Flow	**Quantity per year**	**U.m.**
Pre-treatment			
Feed/Product/ by-product	**Water**	**150,000**	**t/y**
	Ferrous material recovered	**11,538.4615**	**t/y**
	Non-ferrous material recovered	**5769.23**	**t/y**
Utilities	**Energy**	**11,585.67**	**MWh/y**
Emissions	**Effluent**	**657,692.31**	**t/y**
Incinerator			
Feed/Product/ by-product	**RDF**	**300,000**	**t/y**
	Heat	**179,850**	**MJ/y**
	Electricity	**791,340**	**MJ/y**
Emissions	**CO2 (fossil)**	**203,050.2**	**t/y**
	CO2 (biogenic)	**165.679,8**	**t/y**

Pre-treatment (same data as in the previous table)			
Gasifier			
Feed/Product/by-product	RDF	300,000	t/y
	Granulated	72,960	t/y
	Methane	27,689.7	t/y
Utilities	Nitrogen	20,000,000	Nm3/y
	Oxygen	Totally supplied as co-product of electrolysis	
	Natural gas	15,696.43	t/y
Refinery			
Feed/product/by-product	Syngas feedstock	493,361.1	t/y
	Syngas feedstock (CH4 excluded)	465,671.4	t/y
	Methanol production	409,822	t/y
	Sulfur cake	2,550	t/y
	Electric power	259,059	MWh/y
	E. P. for electrolysis	1,462,500	MWh/y
	Weel water	786,450	m3/y
	Demi water	275,295	m3/y
	Boiler Feeding Water	456,427	m3/y
	Low pressure steam	197,350	t/y
	Instrument air	15,787,500	Nm3/y
	Cooling water	70,945,031	m3/y
Waste	Sludge	11,750	t/y
Emissions	Water	72,463,203	m3/y

III Results - Percentage Differences

Impact category	Zero vs WtE	Zero vs WtM-E	WtE vs WtM-E
Global Warming (GW)	-44%	-81%	-66%
Stratospheric Ozone Depletion (SOD)	159%	-63%	-86%
Ionising Radiation (IR)	-1073%	16122%	1465%
Ozone Formation, Human Health (OFH)	-518%	1017%	249%
Fine Particulate Matter Formation (FPMF)	-296%	909%	304%
Ozone Formation, Terrestrial ecosystems (OFT)	-517%	1228%	283%
Terrestrial Acidification (TA)	-281%	715%	261%
Freshwater Eutrophication (FE)	-93%	-70%	363%
Marine Eutrophication (ME)	-97%	-88%	296%
Terrestrial Ecotoxicity (TE)	-272%	7298%	2035%
Freshwater Ecotoxicity (FET)	-30%	-69%	-56%
Marine Ecotoxicity (MET)	-31%	-69%	-55%
Human Carcinogenic Toxicity (HCT)	31%	474%	339%
Human non-carcinogenic toxicity (HNCT)	-42%	-78%	-63%
Land Use (LU)	-267%	2640%	793%
Mineral Resource Scarcity (MRS)	-407%	12317%	2511%
Fossil Resource Scarcity (FRS)	-304%	-4659%	-1078%
Water Consumption (WC)	-384%	42444%	8858%

Zero vs WtE

Better performance of Waste to Energy for 16 impact categories;

IR, OFs and MRS with high differences;

Worst performances for SOD and HCT.

Zero vs WTM-E

Better performance of Waste to Methanol for 8 categories;

FRS with high differences;

Worst performances for IR, MRS, TE and WC.

WtE vs WtM-E

Better performance of Waste to Methanol for 6 categories;

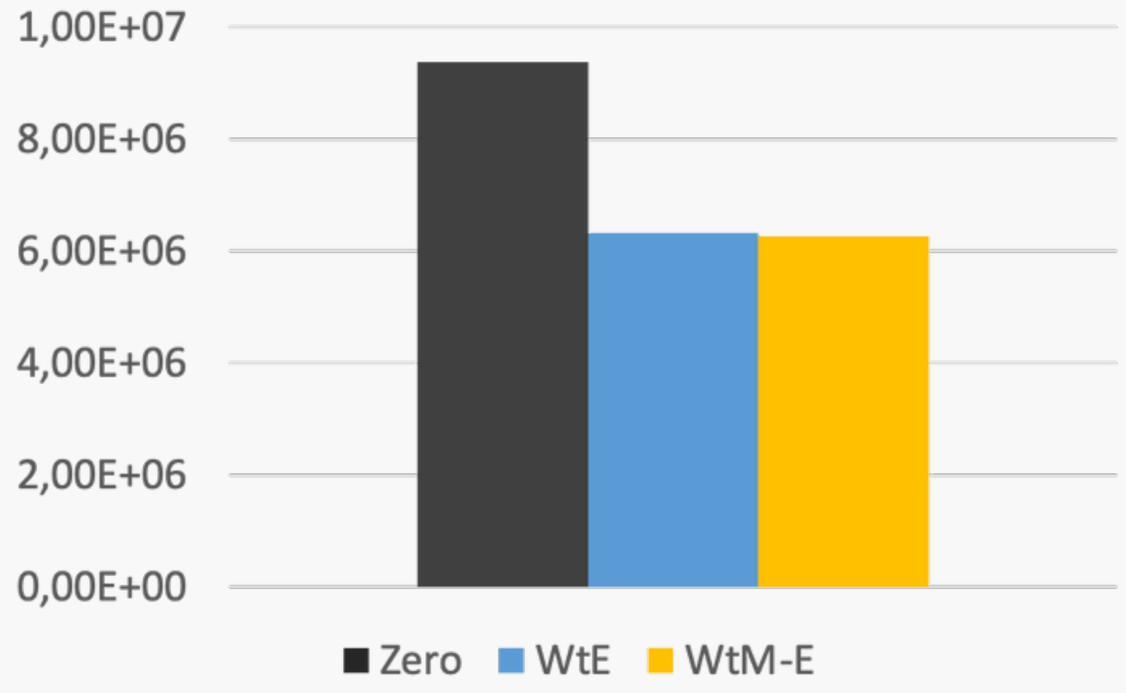
Less impact to GW and FRS;

Worst performances for WC, MRS and TE.

III Results - normalization

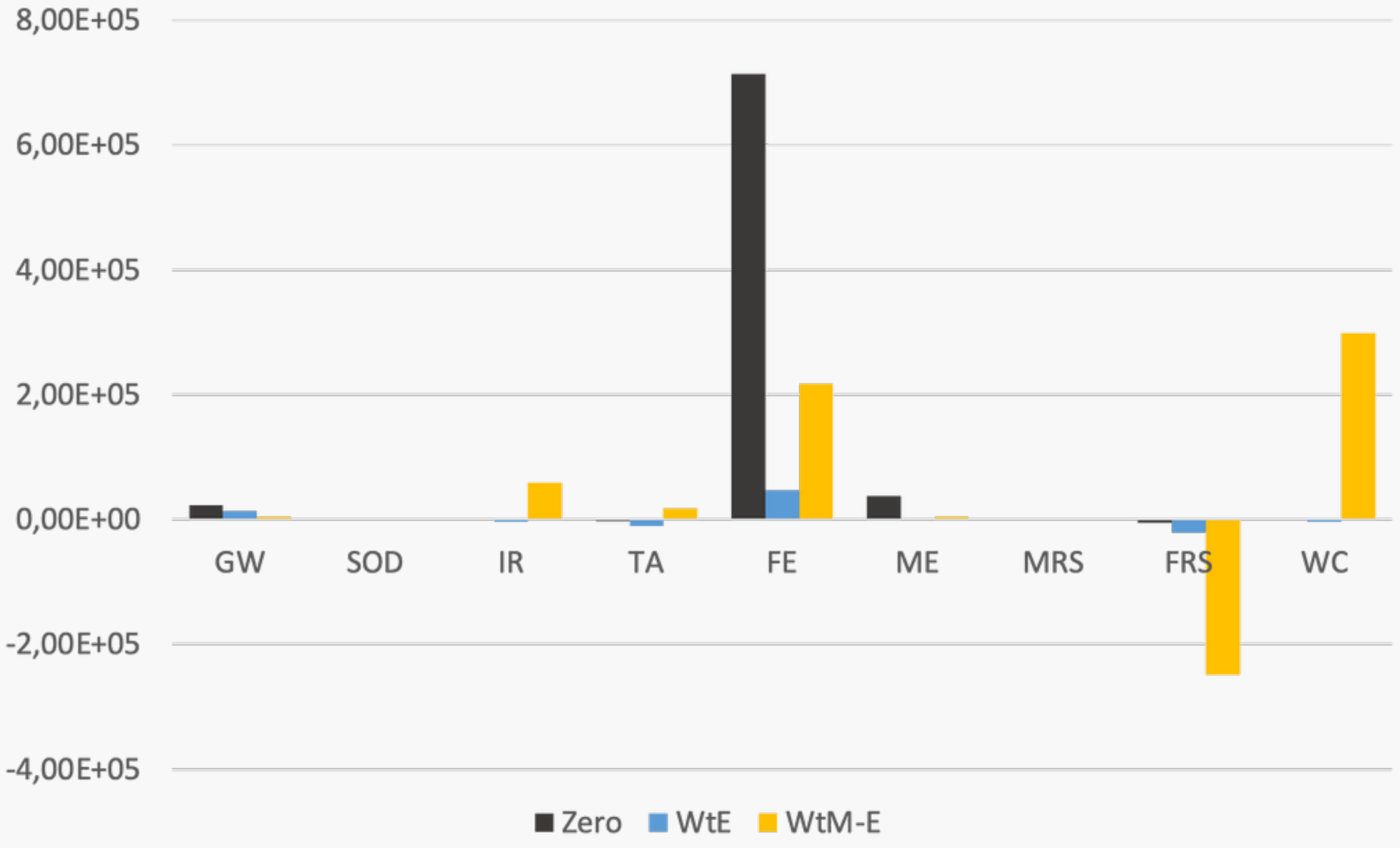
- WtE and WtM-E have comparable environmental potential impact;
- Scenario zero is the worst.

Cumulative impact

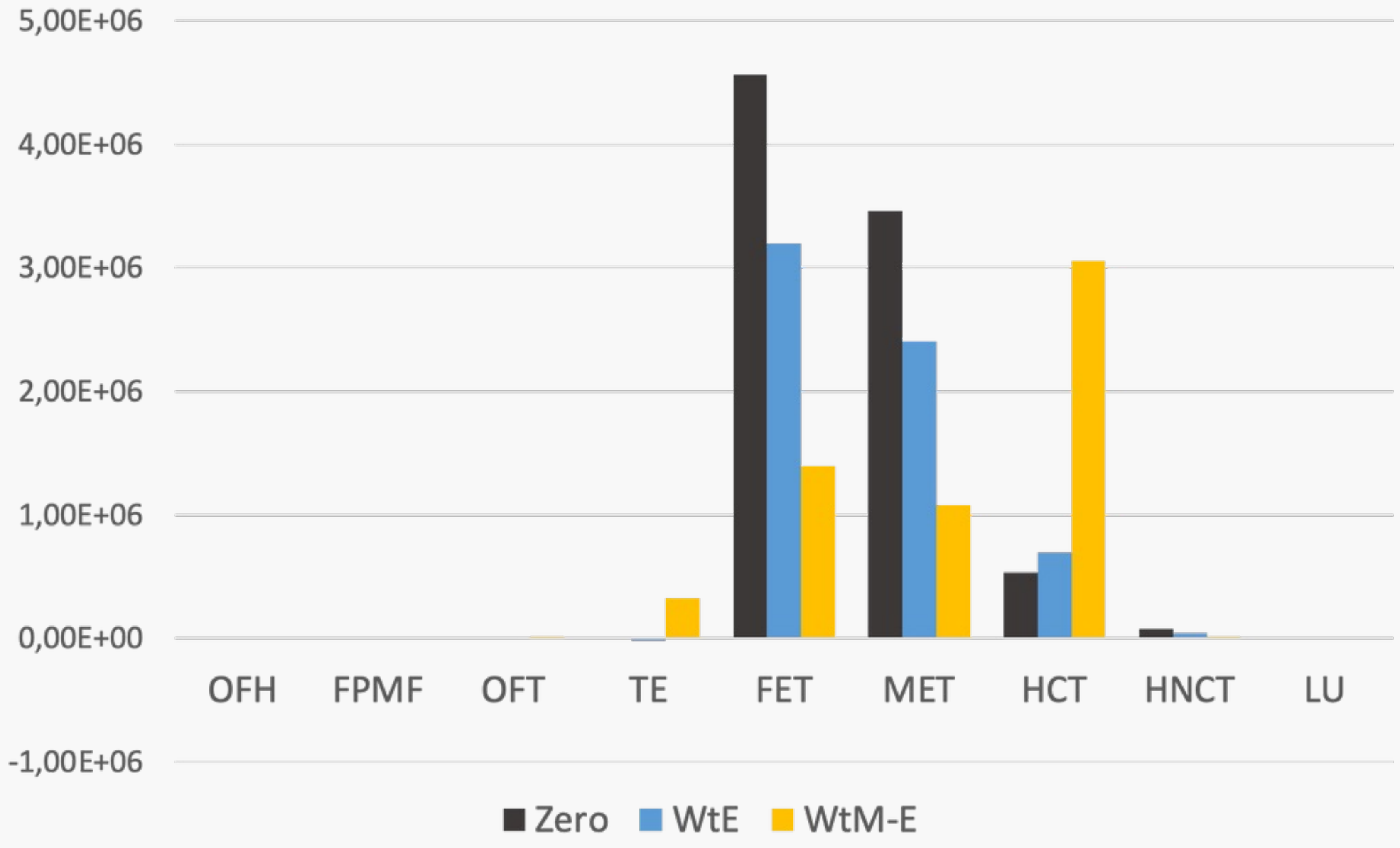


- Considerable better performance of WtE in FE, WC and HCT;
- Considerable better performance of WtM-E in FET, MET and FRS.

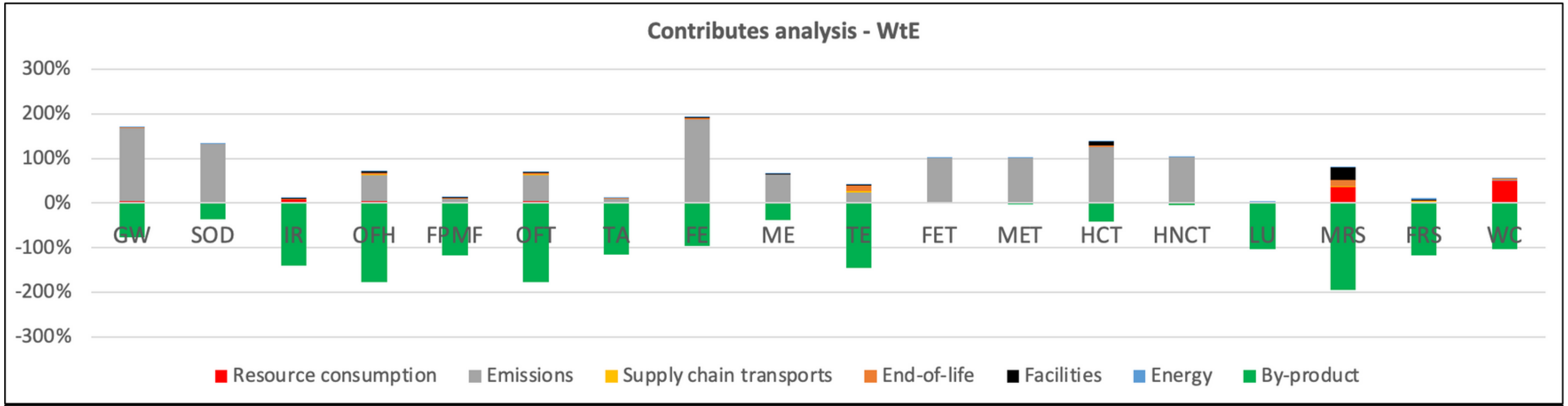
Normalized impacts (1)

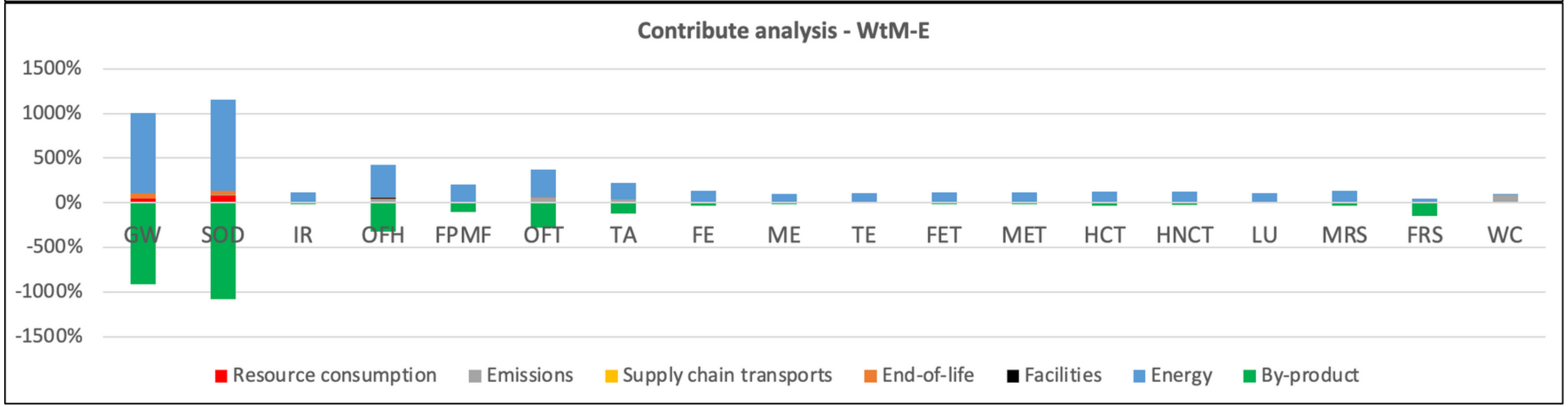


Normalized impacts (2)



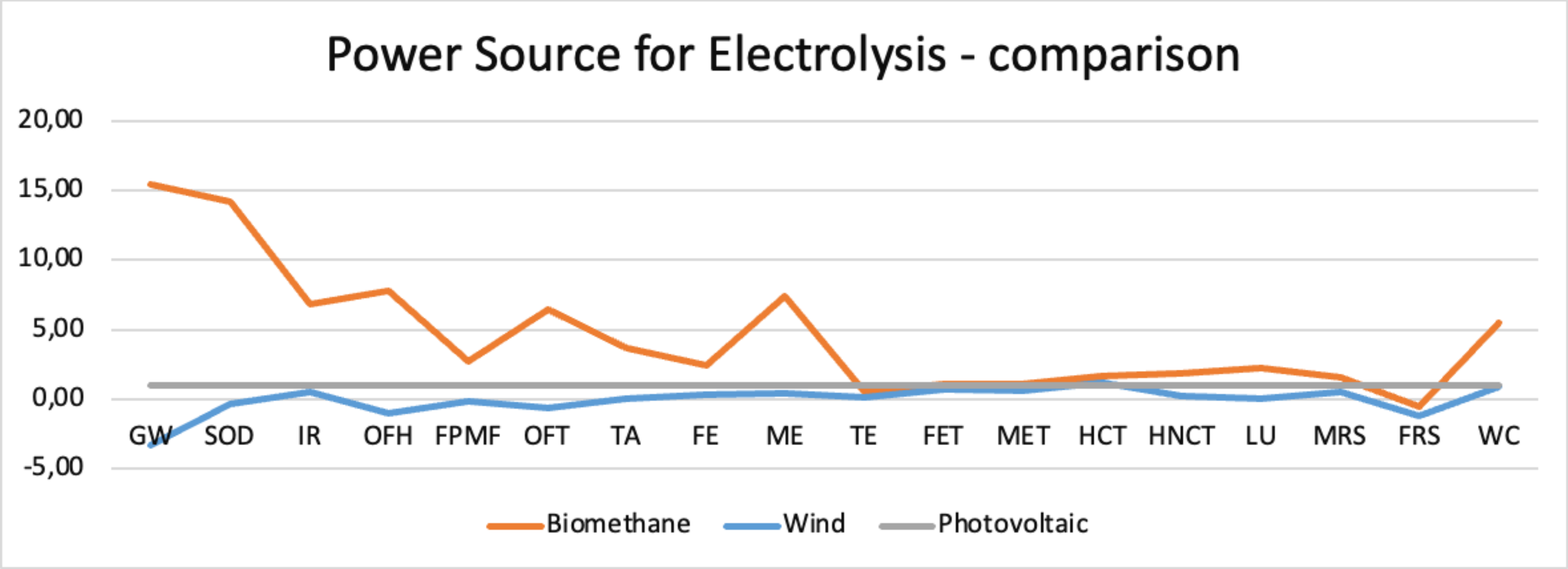
III Results - Contributes analysis





- Emissions are higher contributor in WtE;
- High by-product compensation for GW, SOD and FRS in WtM-E.

III Results - Sensitivity analysis

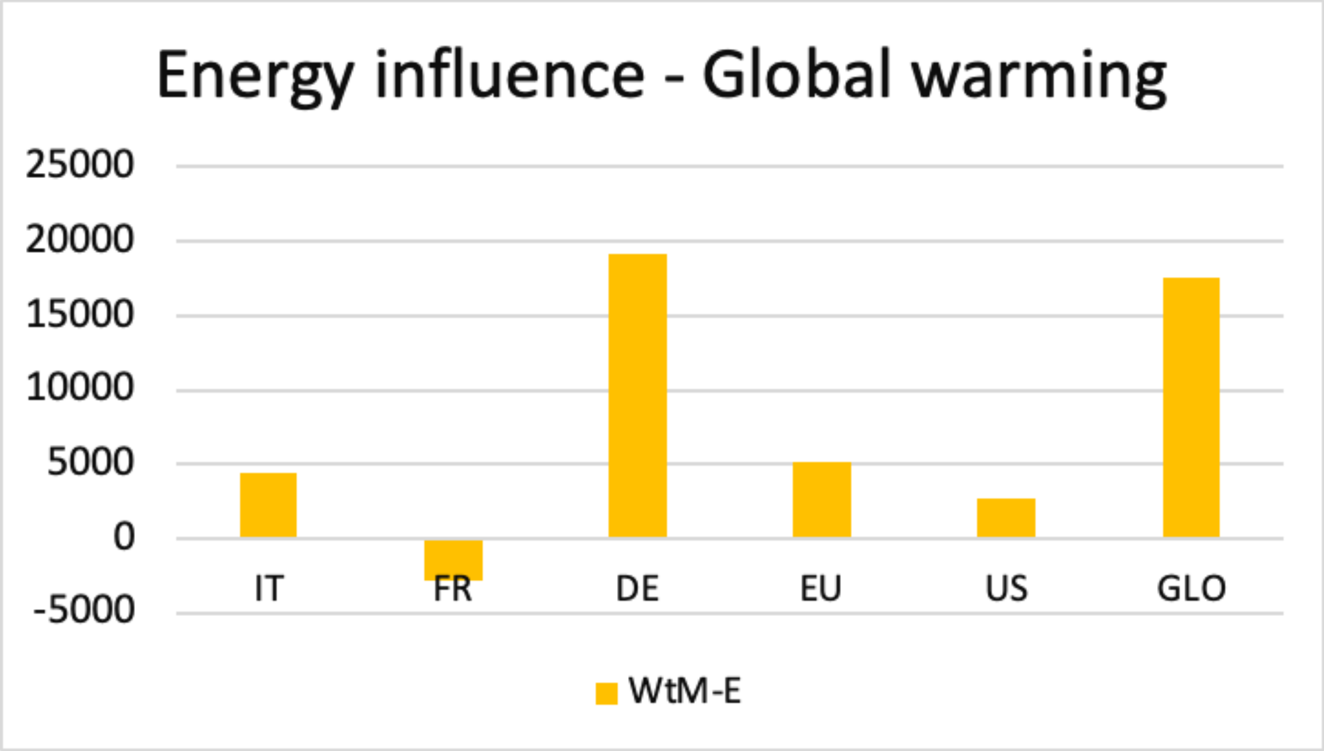


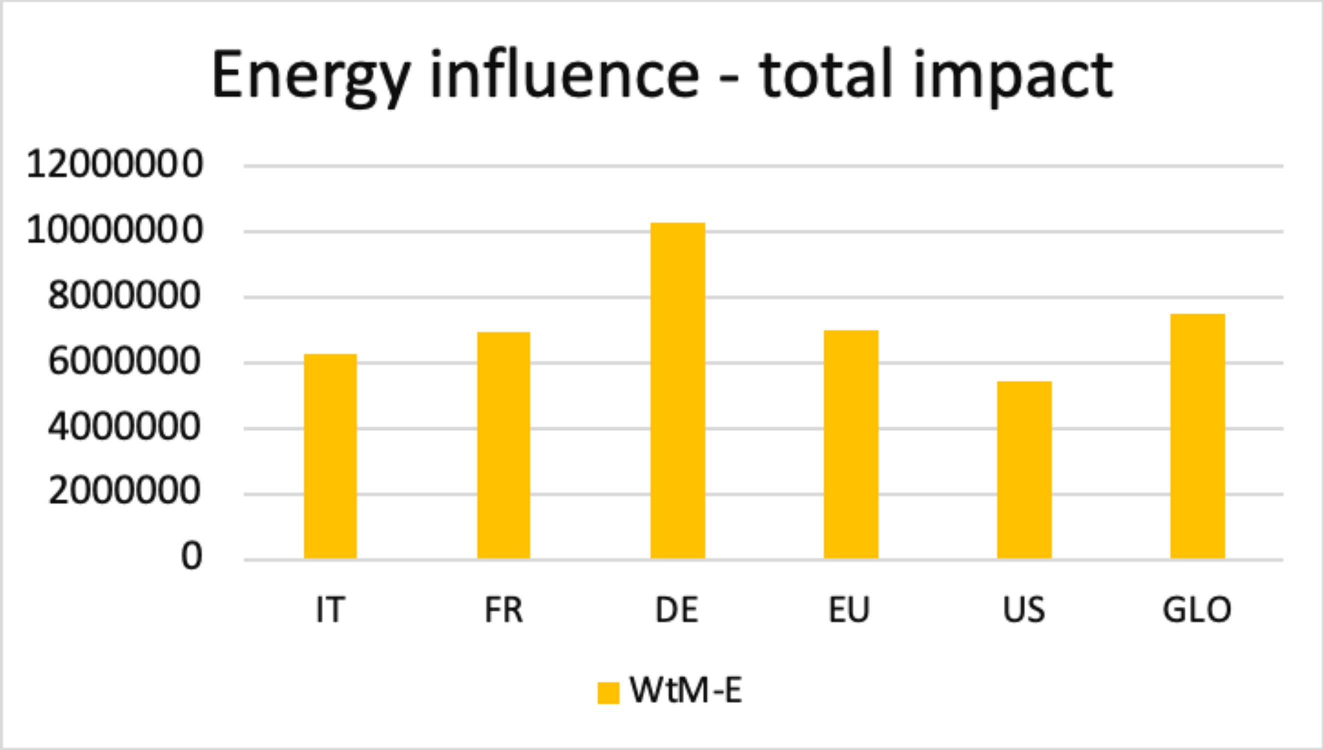
Comparison of different power sources for electrolysis:

- Wind power instead photovoltaic power could reduce all the potential impact, especially GW and FRS;
- Biomethane will not be a friendly power source for electrolysis.

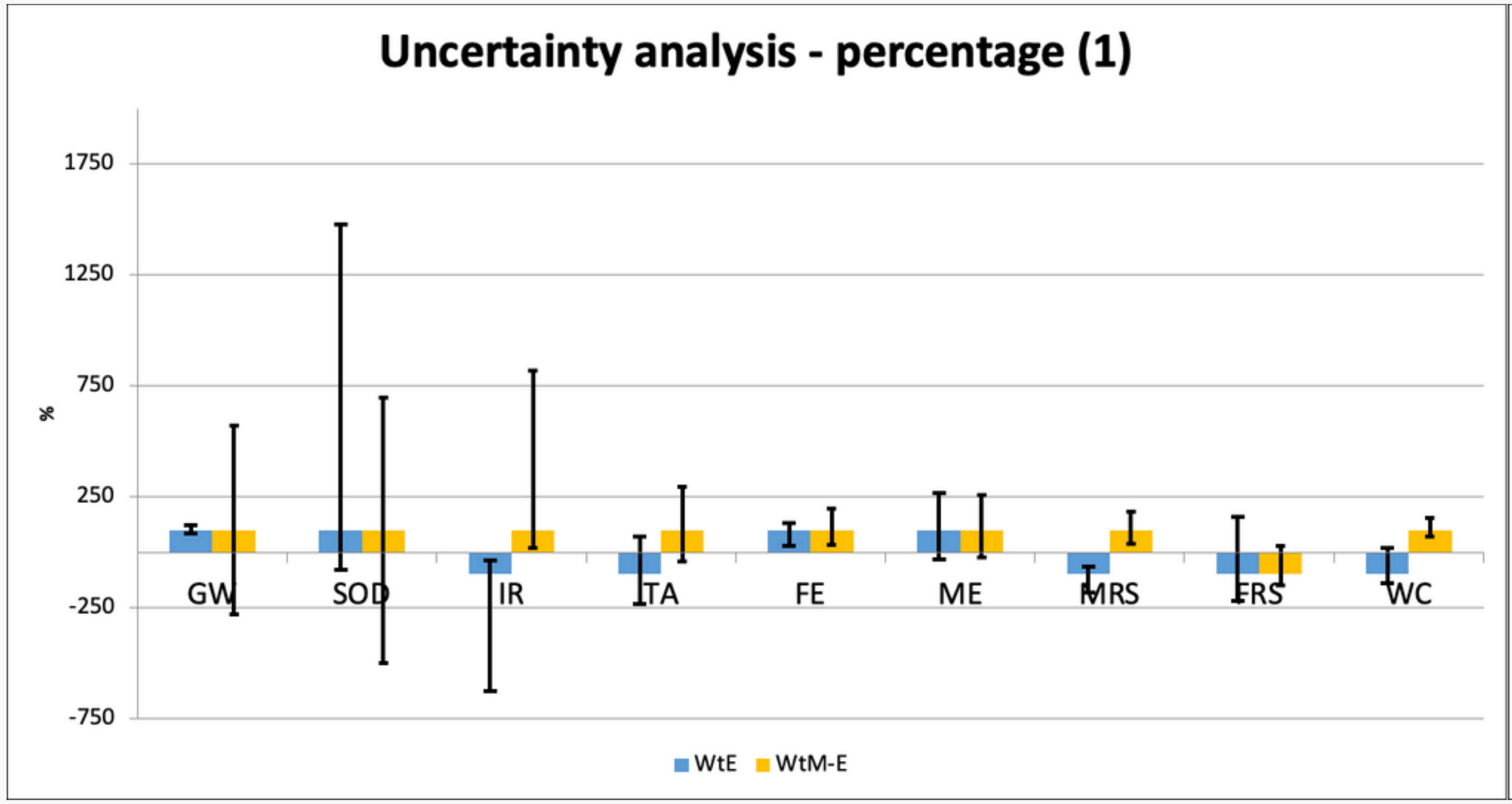
Comparison of different country's energy mixes:

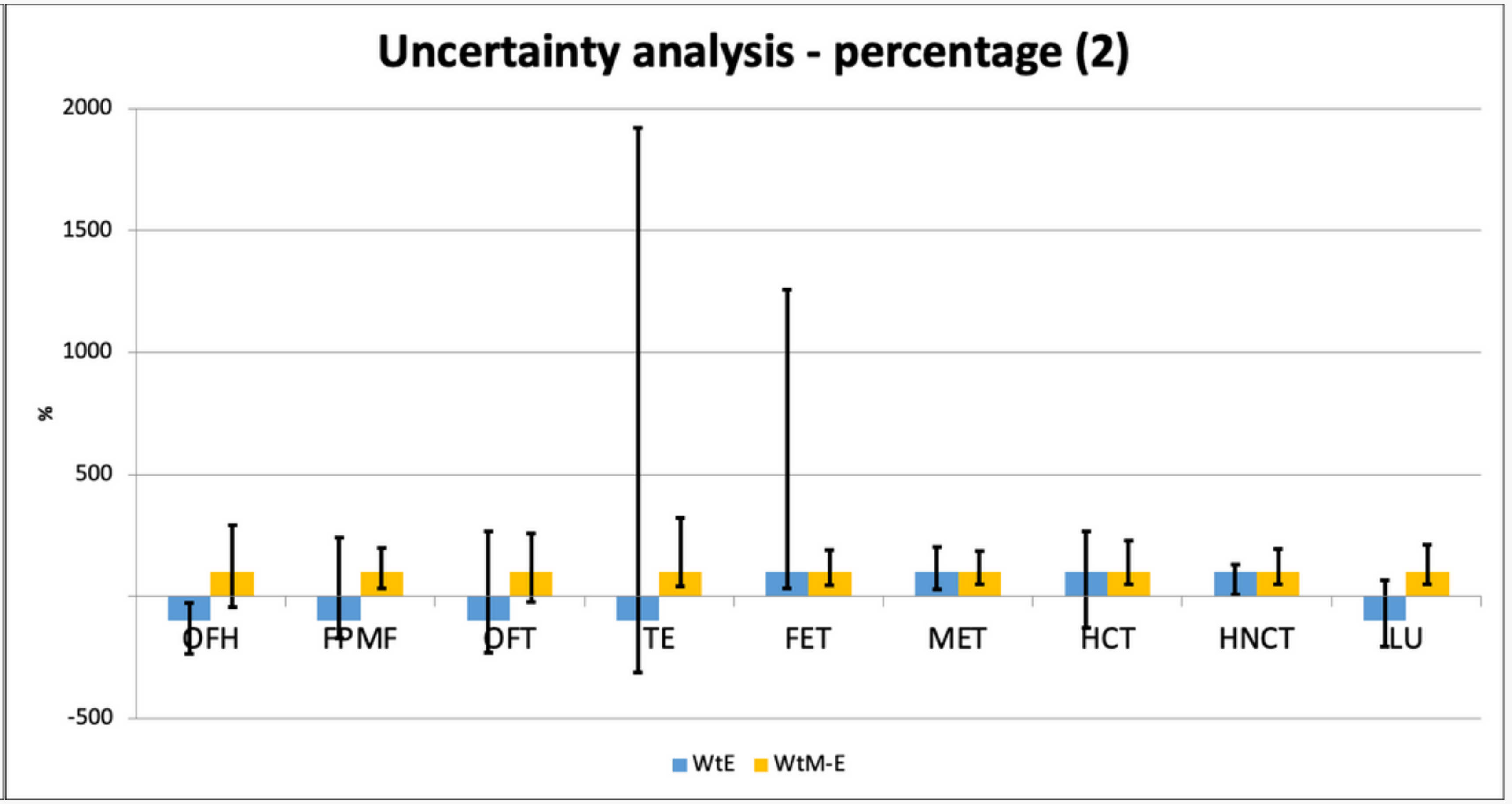
- Carbon negative for FR and similar contribution for IT, EU and US;
- High impact for DE e GLO;
- Total impact comparable for all energy mixes, highest impact reach for DE.





III Results - Uncertainty analysis





- Uncertainty analysis performed with 25.000 run;
- 80.9% of values with known uncertainty;
- Confidence interval set at 95%.

- WtM-E affected by high uncertainty for GW, SOD and IR;
- WtE affected by high uncertainty for SOD, IR, TE and FET;
- Most impact categories have an uncertainty shifted up.

IV Discussions

- Zero-scenario identified as the worst scenario, Waste to Methanol and Waste to Energy identified as comparable scenarios with comparable total impacts:
    - Zero → 9.38×10^6
    - WtE → 6.33×10^6
    - WtM → 6.27×10^6

- Waste to Methanol is better especially for Global Warming and Fossil Resource Scarcity, thanks to the methanol production, but affected by a high uncertainty in GW;
- As reported by Tenhumberg et al, the energy consumption of electrolysis is affected by high uncertainty (5.0–6.5 $kWh_{el}/Nm^3\ H_2$);
- Waste to Energy scenario has less Water and Mineral Resource Consumption;
- Differences of total impact are related mainly to less local impacts for WtM (FET and MET).

IV Discussions

- Emissions are the higher contributors for WtE, partially compensated by heat and electricity produced;
- Poor contribution of resources production to WtM scenario, due to the auto-production of oxygen and hydrogen thanks to electrolysis;
- Global warming is reduced with waste to methanol, thanks to the high amount of methanol produced due to the total conversion of Carbon (biogenic and fossil);
- Sensitivity analysis has also highlighted the importance of energy sources for environmental assessment: plant location and relative energy mix have an influence on total impacts and higher on GW, highlighting the need for ad hoc assessments for each plant to high power intensity;
- High water consumption could be reduced by a circular water system.

V Conclusions

- Have been compared 300,000 t of RDF obtained from secondary wastes, of which only 30% valorised energetically;
- Compared scenario: Zero-Scenario, Waste to Energy and Waste to Methanol;
- Criticalities:
  - Lack of data for WtM at the industrial scale, while WtE is a well-known and assessed process;
  - Background data of WtM, available in Ecoinvent, are related to a pilot plant;
- WtM represents a potential road for the decarbonization of the waste management sector, but:
  - It's necessary an electrolysis plant for hydrogen and oxygen production;
  - Hydrogen has to be green, with renewable power sources;
  - PV energy production is characterized by the extensive impact on Land Use (35.2 km^2 eq);
  - More studies about the process and a complete Life Cycle Sustainability Assessment are needed.

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