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„Thin-layer drying kinetics of tomato waste for biorefinery purposes – an LCA perspective"

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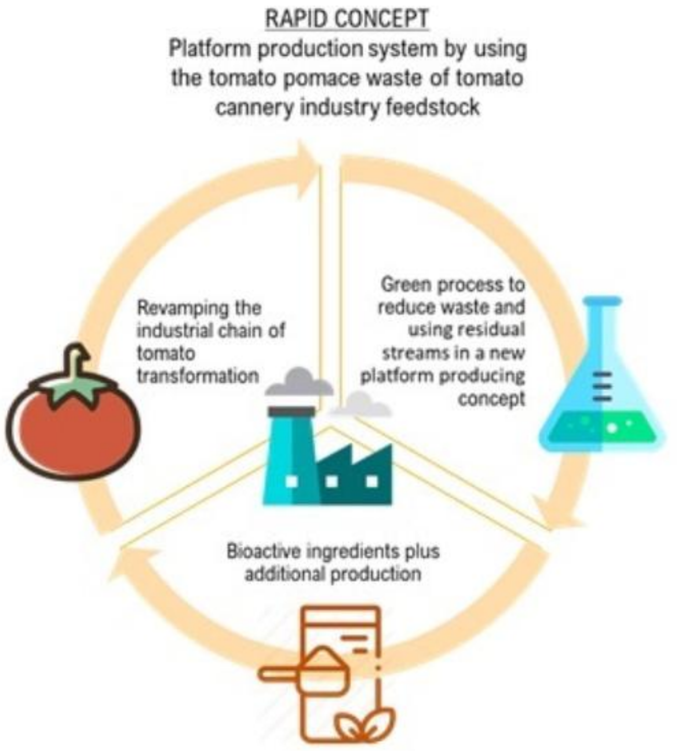
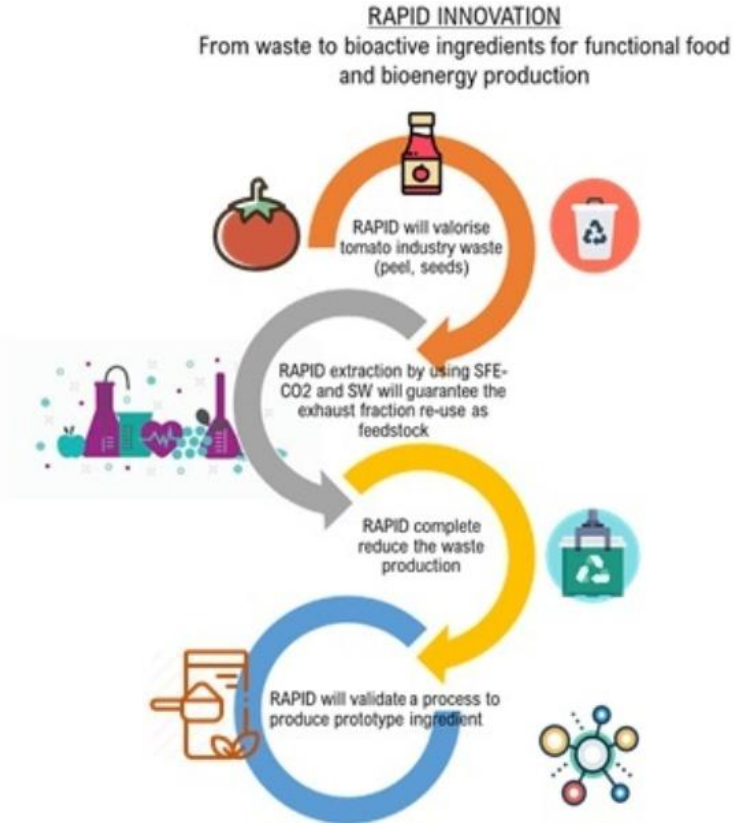
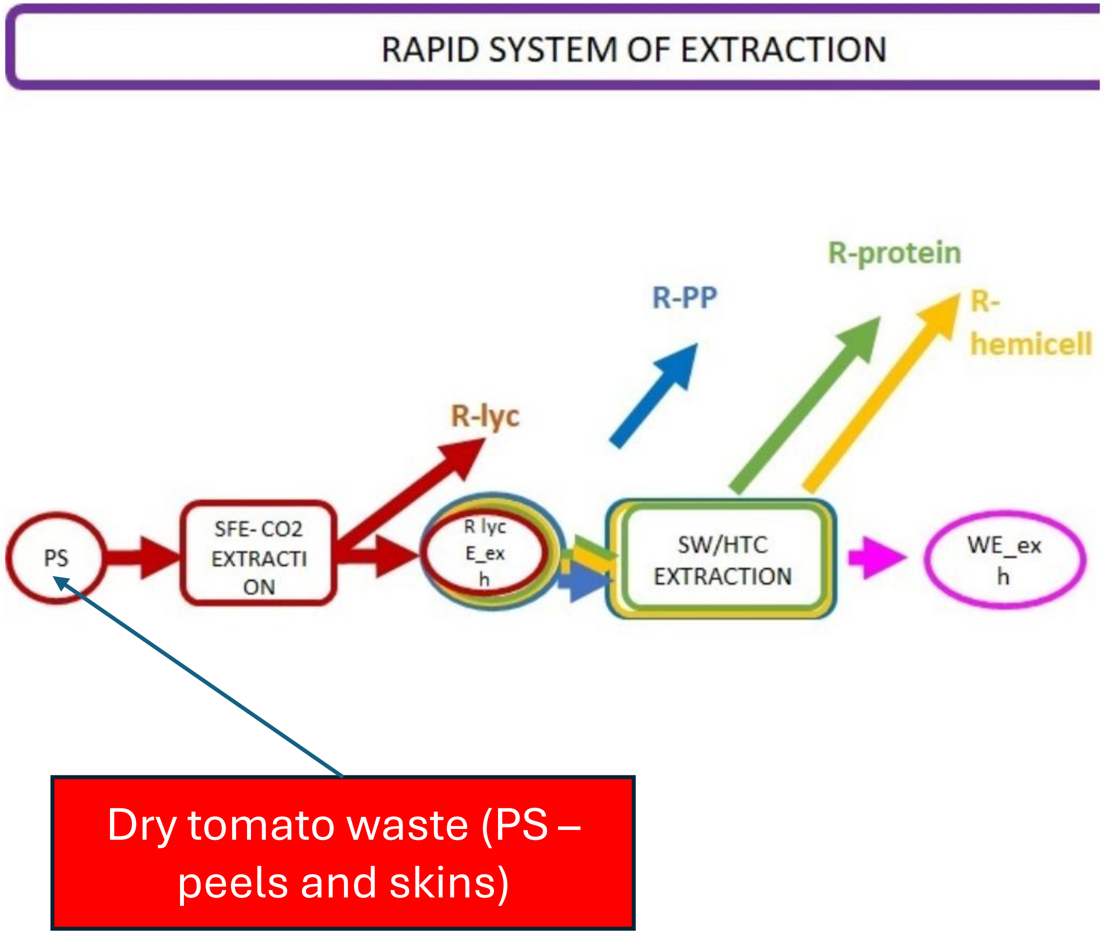
MOTIVATION

Project: “From tomato industry waste development of a platform for the production of bioactive ingredients. RAPID (fRom wAste Platform bIoactive ingreDient)”.







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METHODOLOGY

Experimental investigation → **Process modelling** → **Life Cycle Assessment (LCA)**

- Thin-layer drying at various temperatures:
  120, 105, 90, and 75 °C
- Mass loss data recorded
- Laboratory-scale
- Heat supplied by radiation
- Layer thickness of approx. 5 mm

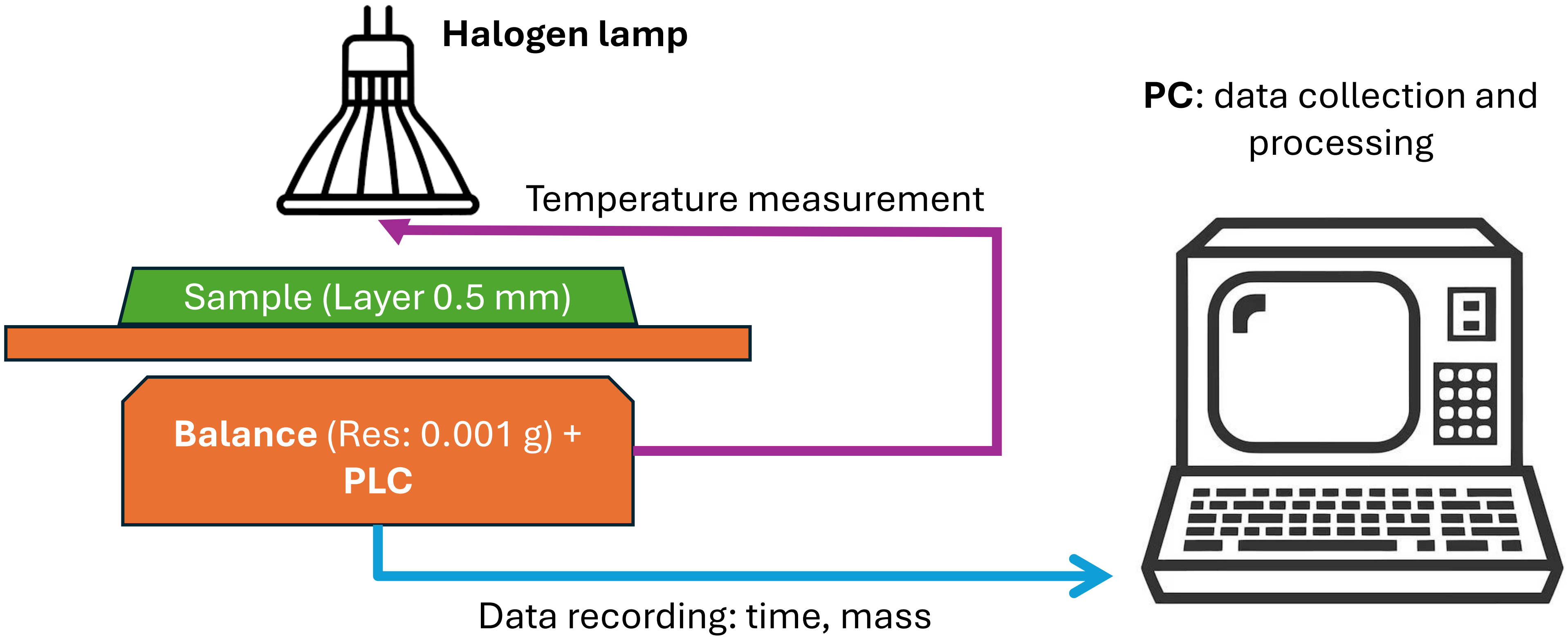
- Empirical models:
  Lewis, Page, Midilli, Henderson and Pabis, Modified Page
- Eperimental data fitted by non-linear regression
- Root mean square error (RMSE) used for assessing how well theexperimental data are fitted
- Fitting objective: minimisation of RMSE

- **Prospective LCA**
- EN ISO 14040 and 14044
- Functional unit: 1 kg of evaporated water
- Databases: Environmental Footprint 3.1 and Econinvent 3.8
- LCIA method: Environmental Footprint 3.1
- Software: openLCA
- Impact of capital goods included
- Lenght Scale Factor, based on kinetics, used for estimation of capital goods
- Existing dryer used as a proxy

Prospective LCA

- Forward-looking life cycle approach for ex-ante assessment of future environmental impacts
- Serves different purposes relating to innovative technologies/ processes/ products (e.g., informing early design stage)

METHODOLOGY - Experimental



METHODOLOGY - Kinetics

$$MR = \frac{M_t - M_e}{M_o - M_e}$$

Common Simplification

$$MR = \frac{M_t}{M_o}$$

Commonly used thin layer drying kinetics models

Model name	Model equation
Page	$MR = \exp(-kt^n)$
Midilli et al.	$MR = a\exp(-kt) + bt$
Handerson and Pabis	$MR = a\exp(-kt)$
Modified page	$MR = \exp(-(kt^n))$
Lewis model	$MR = \exp(-kt)$

Abbreviations: k, k_1, k_2, drying constants (s^{-1}); MR, moisture ratio; n, a, b, c, model constants (dimensionless); t, time (s).

M_e, M_o and M_t are the moisture content (% wb) at equilibrium, initial and time t, respectively.

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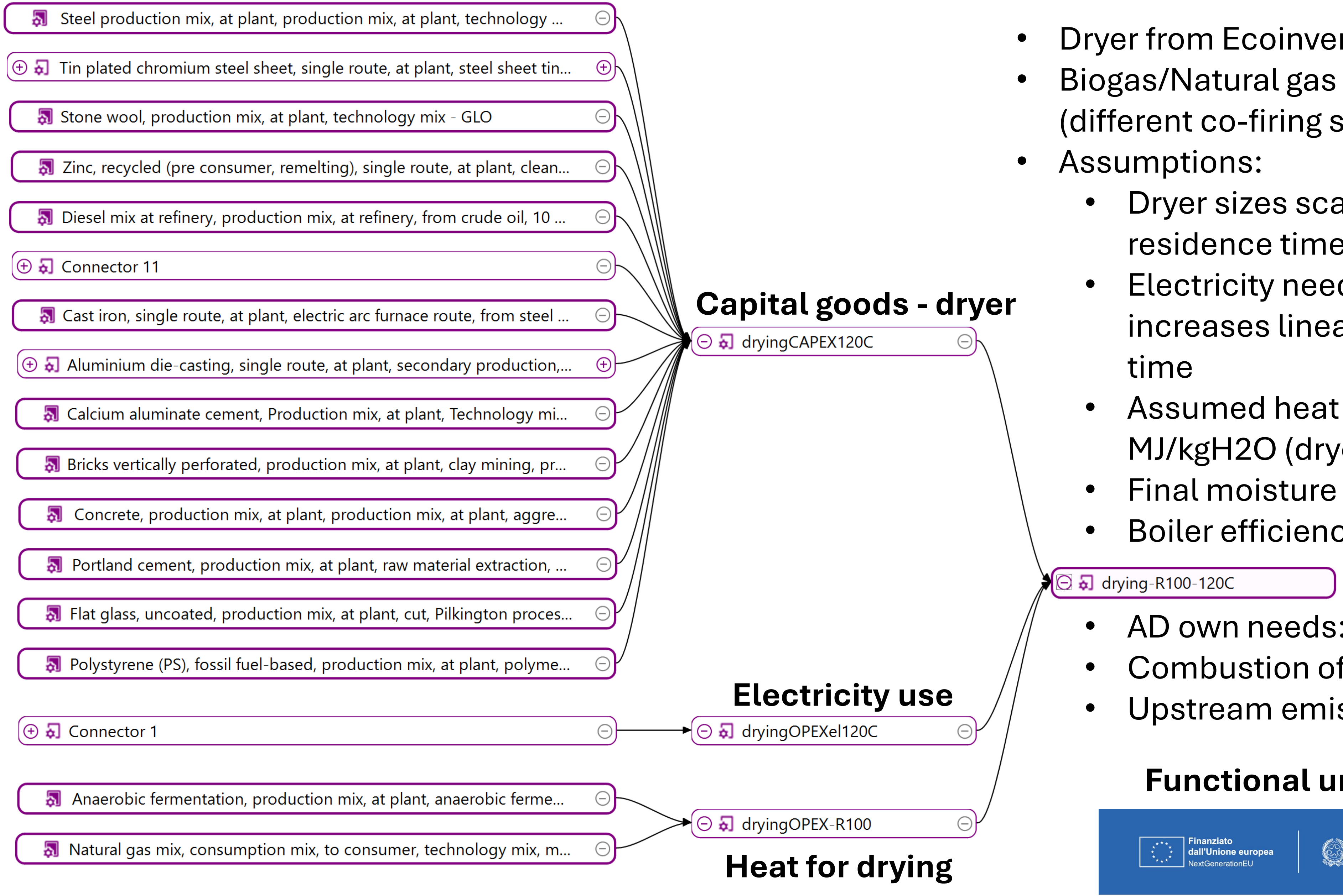
METHODOLOGY – scope - openLCA model



- Dryer from Ecoinvent used as a proxy
- Biogas/Natural gas (NG) used for heat supply (different co-firing scenarios)
- Assumptions:
  - Dryer sizes scales linearily with required residence time (for capital goods)
  - Electricity needed for the dryer also increases linearly with required residence time
  - Assumed heat required for drying 4.79 MJ/kgH2O (dryer efficiency 55%)
  - Final moisture content of PS 15%
  - Boiler efficiency 90%

- AD own needs: 20% of biogas (LHV based)
- Combustion of NG: 0.055 kgCO2eq/MJ of NG
- Upstream emissons from databases

Functional unit: 1 kg of evaporated water

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RESULTS - kinetics

		75 °C			90 °C			105 °C			120 °C		
		Avg.	**+/-**	**%**	**Avg.**	**+/-**	**%**	**Avg.**	**+/-**	**%**	**Avg.**	**+/-**	**%**
Lewis	**k**	1.19E-04	5.39E-06	4.5	1.66E-04	7.60E-06	4.6	2.80E-04	5.85E-05	20.9	3.49E-04	2.27E-05	6.5
Page	**k**	2.65E-07	4.83E-07	182.0	4.25E-05	7.84E-05	184.5	4.17E-09	2.23E-09	53.6	2.37E-09	9.55E-11	4.0
	n	1.88E+00	2.31E-01	12.3	1.46E+00	4.15E-01	28.3	2.38E+00	2.66E-02	1.1	2.50E+00	1.92E-02	0.8
Midilli	**a**	7.13E-01	1.85E-02	2.6	7.06E-01	4.91E-02	7.0	7.13E-01	5.75E-02	8.1	8.90E-01	2.02E-02	2.3
	b	-1.99E-04	4.35E-06	2.2	-2.51E-04	4.13E-05	16.4	-3.98E-04	7.07E-05	17.8	-3.45E-04	5.10E-06	1.5
	k	-5.34E-02	4.11E-03	7.7	-6.64E-02	1.12E-02	16.8	-7.34E-02	8.27E-03	11.3	-5.56E-02	1.06E-02	19.1
	n	3.27E-01	3.92E-03	1.2	3.06E-01	3.19E-03	1.0	3.07E-01	1.33E-02	4.3	2.59E-01	3.78E-02	14.6
Henderson&Pabis	**a**	1.23E+00	7.95E-03	0.6	1.26E+00	2.52E-03	0.2	1.34E+00	2.26E-02	1.7	1.53E+00	2.41E-02	1.6
	k	1.53E-04	8.33E-06	5.4	2.17E-04	1.10E-05	5.1	3.88E-04	8.59E-05	22.2	5.30E-04	3.97E-05	7.5
Modified Page	**n**	2.72E+00	3.55E-02	1.3	2.67E+00	1.03E-01	3.8	2.74E+00	5.65E-02	2.1	2.80E+00	3.61E-02	1.3
	k	1.32E-04	4.85E-06	3.7	1.81E-04	9.90E-06	5.5	2.98E-04	5.95E-05	20.0	3.61E-04	2.21E-05	6.1

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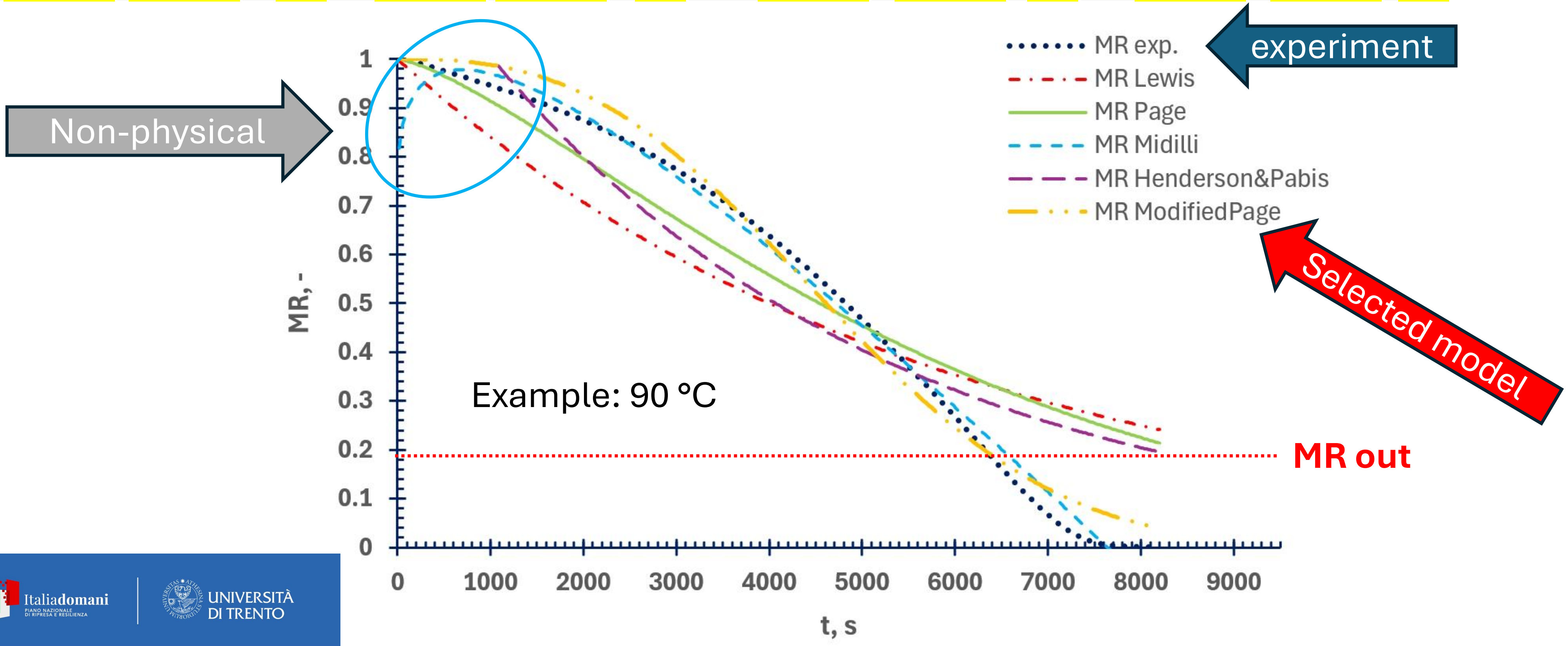
RESULTS – model selection

RMSE:	75 °C			90 °C			105 °C			120 °C		
	Avg.	+/-	%	Avg.	+/-	%	Avg.	+/-	%	Avg.	+/-	%
Lewis	0.1569	0.0014	0.9	0.1568	0.0050	3.2	0.1645	0.0014	0.9	0.1739	0.0020	1.2
Page	0.0741	0.0186	25.2	0.1249	0.0281	22.5	0.0461	0.0034	7.5	0.0454	0.0005	1.1
Midilli	0.0284	0.0030	10.6	0.0287	0.0014	4.8	0.0383	0.0034	8.9	0.0515	0.0029	5.6
Henderson&Pabis	0.1287	0.0043	3.3	0.1276	0.0051	4.0	0.1269	0.0032	2.5	0.1215	0.0023	1.9
Modified Page	0.0392	0.0020	5.0	0.0388	0.0035	8.9	0.0380	0.0020	5.2	0.0386	0.0013	3.3



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RESULTS - LCA

	Scenario name	T drying	Total impact	CAPEX subtot	
		°C	kg_{CO2eq}/kg_{H2O}	kg_{CO2eq}/kg_{H2O}	%
F100	***100% Fossil fuel***	120	0.383	0.016	4.1
		75	0.428	0.043	10.0
B	***Baseline***	120	0.334	0.016	4.7
		75	0.38	0.043	11.3
R100	***100% renewable***	120	0.093	0.016	16.9
		75	0.138	0.043	31.2

Impact of capital goods

Absolute

Relative

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RESULTS

drying-R100-75C

Flow: - Emissions to air/Emissions to air, unspecified

Impact category: Climate change

<u>Scenario with highest share of capital goods</u>

Contribution	Process	Required amount	Total result [kg CO2 Equivalents]	Direct contribution [kg CO2 Equivalents]
100.00%	drying-R100-75C	1.00000 kg	0.13779	
48.44%	dryingOPEX-R100	1.00000 kg	0.06675	
31.17%	dryingCAPEX75C	1.00000 kg	0.04295	
05.17%	Steel production mix, at plant, ...	0.00374 kg	0.00712	0.00712
04.95%	Flat glass, uncoated, productio...	0.00503 kg	0.00682	0.00682
04.69%	Aluminium die-casting, single ...	0.00034 kg	0.00647	0.00010
04.47%	Tin plated chromium steel she...	0.00036 kg	0.00616	7.62234E-5
02.58%	Bricks vertically perforated, pr...	0.01199 kg	0.00355	0.00355
02.38%	Calcium aluminate cement, Pr...	0.00368 kg	0.00327	0.00327
02.06%	Cast iron, single route, at plant,...	0.00194 kg	0.00284	0.00284
01.88%	Polystyrene (PS), fossil fuel-bas...	0.00060 kg	0.00259	0.00259
Dryer 01.46%	Portland cement, production ...	0.00235 kg	0.00202	0.00202
00.98%	Stone wool, production mix, at...	0.00148 kg	0.00135	0.00135
00.23%	Diesel mix at refinery, producti...	0.02498 MJ	0.00031	0.00031
00.21%	Connector 11	0.00423 MJ	0.00028	
00.12%	Zinc, recycled (pre consumer, r...	0.00060 kg	0.00017	0.00017
00.00%	Concrete, production mix, at pl...	3.13386E-5 kg	4.44634E-6	4.44634E-6
20.39%	dryingOPEXel75C	1.00000 kg	0.02809	

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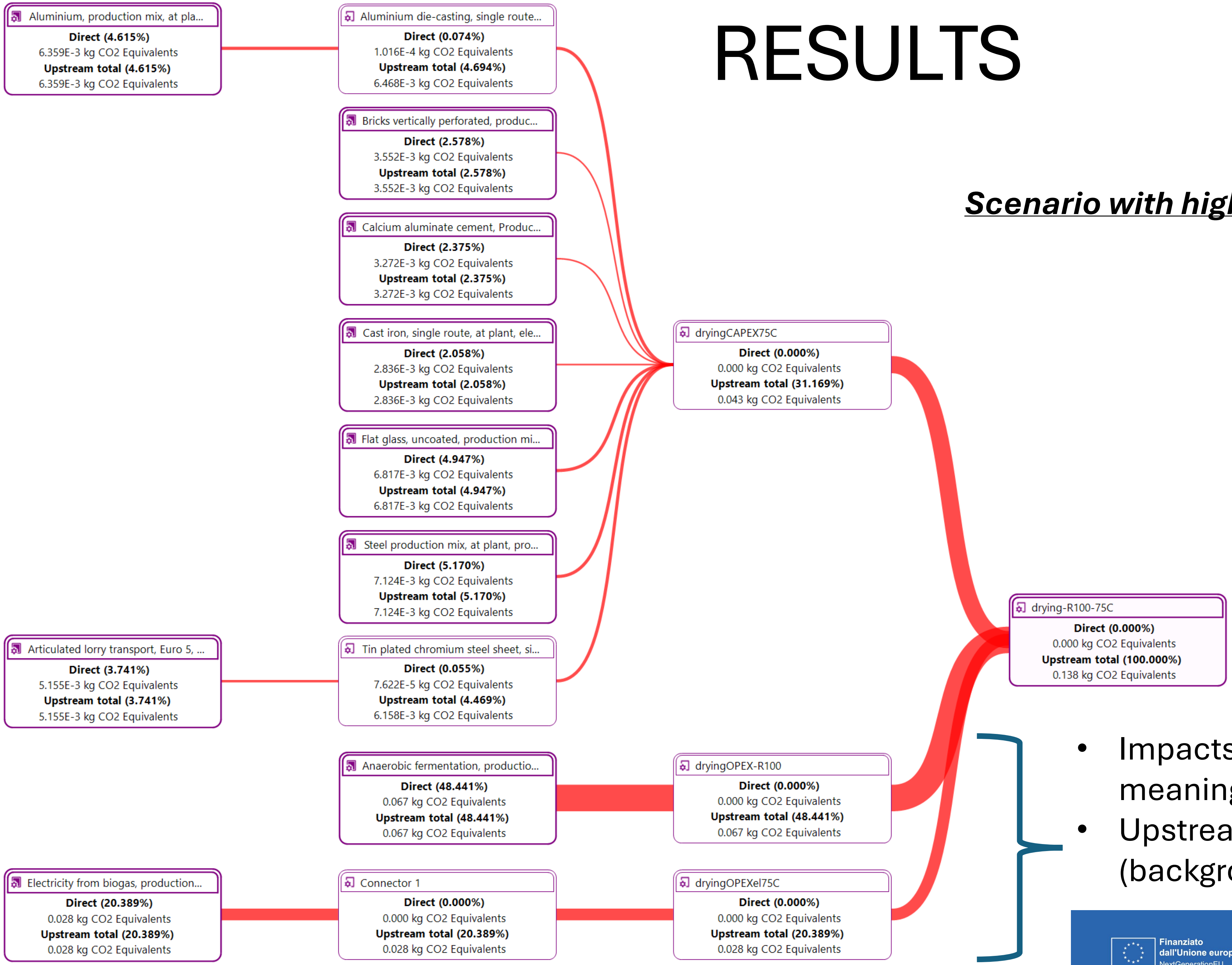
RESULTS

Scenario with highest share of capital goods



- Impacts from energy consumption still meaningful
- Upstream impacts of anaerobic digestion (background data from EF 3.1) dominates

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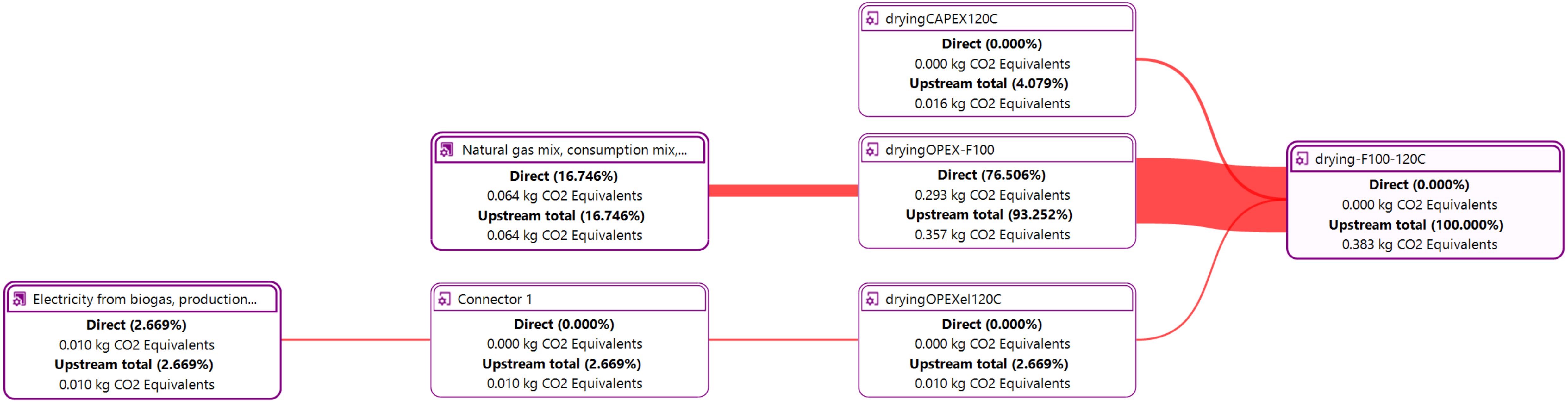
RESULTS

Scenario with lowest share of capital goods



- Impacts from the use of natural gas dwarfs all other impacts
- Upstream impacts from natural gas (background data from EF 3.1) cannot be disregarded

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CONCLUSIONS and FUTURE WORK

CONCLUSIONS:

- Modified Page model most suitable for drying kinetics of PS
- Limited availability of LCA background data for drying - signifficant gap
- Environmental cost of capital goods could be signifficant, especially for low-temperature drying
- Choices made during construction of the building for the dryer could have signifficant influence on environmental impact of the installation
- Capital goods importance increases with increased use of biogas
- Impacts from the use of natural gas dwarfs all other impacts
- Measurements in real conditions (industrial scale) needed to confirm if the kinetics determined for thin-layer on laboratory scale provides reasonable estimation of required residence time (validation needed for different drying technologies)

FUTURE WORKS:

- Include capital goods of biogas plant and boiler
- Include intermediate co-firing scenarios
- Include scenarios with kinetics determined for drying at 90 and 105 °C

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Acknowledgements

- Support from the Rapid project funded by PIANO NAZIONALE DI RIPRESA E RESILIENZA PNRR - Missione 4 “Istruzione e Ricerca” - Componente C2 - Investimento 1.1 “Fondo per il Programma Nazionale di Ricerca e progetti di Rilevante Interesse Nazionale (PRIN 2022 PNRR)” is gratefully acknowledged

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