ANÁLISIS Y SIMULACIÓN
DE PROCESOS AGROALIMENTARIOS

PROSPECTIVE LCA OF FOOD PROCESSING: A CASE STUDY AND SOME INSIGHTS

Neus Sanjuán

Profesor
ASPA Group
Food Technology Department - UPV

UNIVERSITAT
POLITÈCNICA
DE VALÈNCIA

ASSOCIAZIONE
RETE ITALIANA LCA

UPV

OUTLINE

Motivation

Case study on *salmorejo* processing

Some insights

MOTIVATION

- Industrial production of cold tomato soups (*gazpacho Andaluz* and *salmorejo)* is soaring, with more than $100 \cdot 10^6$ L produced in 2021 and a $200 \cdot 10^6$ € turnover.
- Pasteurization is key to extending the shelf life. Novel pasteurization technologies, such as dielectric heating (e.g., radiofrequency-RF), are supposed to be more sustainable and increase product quality.
- No studies available on the application of RF to acidified viscous homogenates that require mild pasteurization temperatures.
- Project **RF-SUSVEG** studied the potential benefits (sensory, nutritional, safety, product shelf-life, eco-efficiency) of continuous flow RF processing vs. conventional heating technologies of *salmorejo* (a highly viscous liquid food).

CASE STUDY ON SALMOREJO PROCESSING

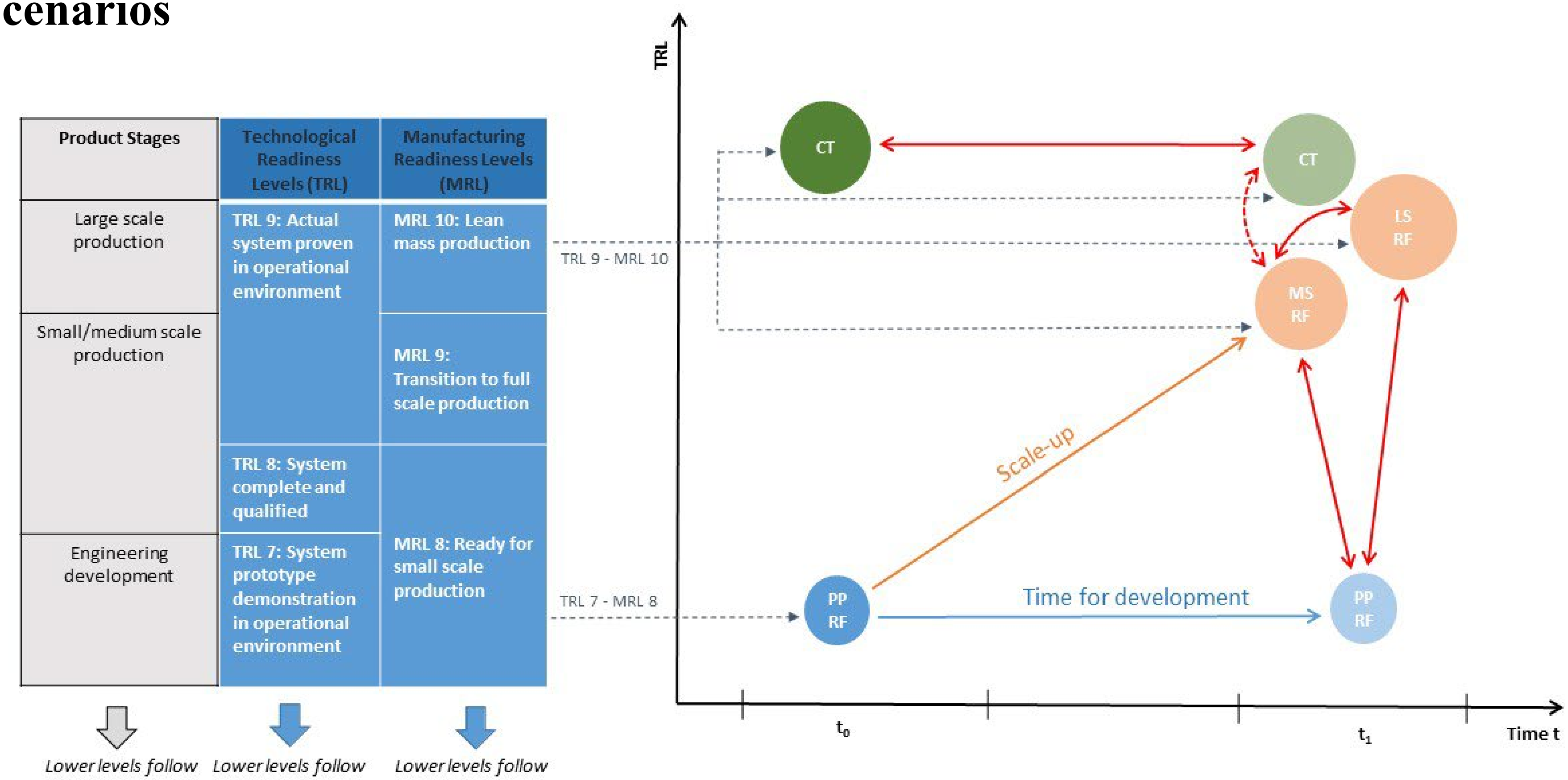
To carry out a prospective LCA of *salmorejo* pasteurized with RF, with a twofold goal:

- to compare its environmental impacts with those of *salmorejo* processed with conventional pasteurization
- to highlight the relevance of upscaling when performing prospective LCAs

Research questions:

1. How does up-scaling affect the environmental impacts of RF processing?
2. Are there relevant differences between RF and conventional pasteurization?
3. Which unit processes and life-cycle stages most contribute to the impacts?
4. How relevant is processing in the *salmorejo* life cycle? and how can its impacts be reduced?

Temporal and technological status of each of the studied scenarios



Product Stages	Technological Readiness Levels (TRL)	Manufacturing Readiness Levels (MRL)
Large scale production	TRL 9: Actual system proven in operational environment	MRL 10: Lean mass production
Small/medium scale production		MRL 9: Transition to full scale production
	TRL 8: System complete and qualified	MRL 8: Ready for small scale production
Engineering development	TRL 7: System prototype demonstration in operational environment	
Lower levels follow	*Lower levels follow*	*Lower levels follow*

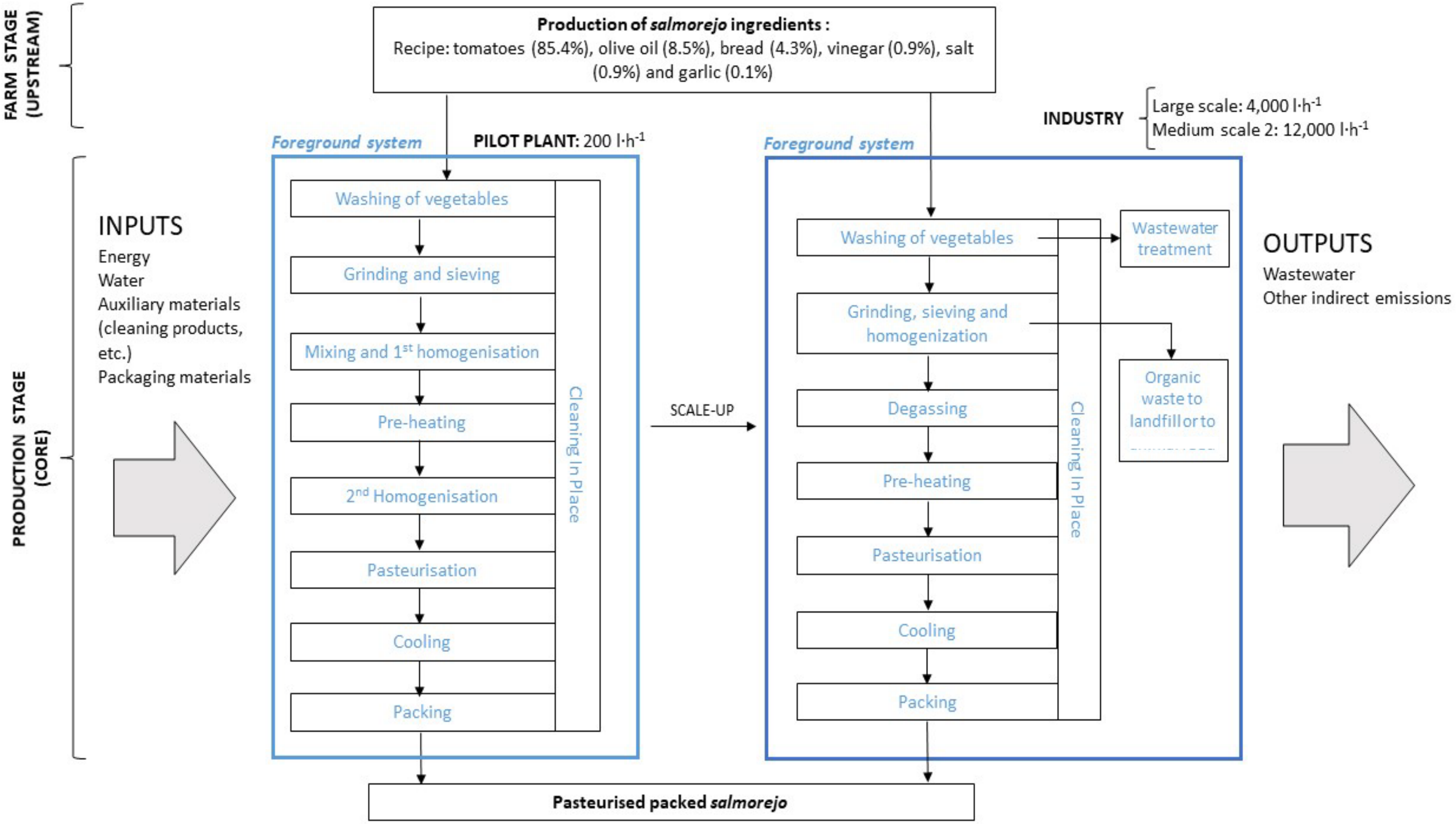
CT, conventional technology; PP, pilot plant; MS, medium scale; LS, large scale; RF, radiofrequency. Continuous red arrow (intra-technology comparison). Dotted red arrow (inter-technology comparison). Dark colour (technology in current time). Light colour (predicted technology).

Adapted from Gavankar et al. (2015), Thonemann et al (2020) and EC.

CASE STUDY: METHODS

- Functional unit: 1 kg pasteurized and packed *salmorejo* (tetrapack*)*
- Previous studies of the project showed that product quality and shelf life are the same, regardless of the pasteurization technology applied; thus, the reference flows are the same.
- System boundaries: “gate-to-gate” and “farm-to-factory-gate”
- Temporal boundaries: year 2035
- Life cycle inventory of foreground system based on upscaling from pilot scale (200 L · h^{-1}) to:
  - medium scale: 4000 L · h^{-1}
  - large scale: 12000 L · h^{-1}
- Life cycle inventory of background system from Ecoinvent 3.8 and GaBi DB v.9.
- Data for Spanish electricity mix and natural gas in 2035 from Navas-Anguita et al. (2020) and Gould and McGlade (2018).

- Impact assessment with ReCiPe 2016 v1.1 Midpoint (H), except for toxicity impacts (UseTox) and blue water scarcity (AWARE)



FARM STAGE (UPSTREAM)

Production of *salmorejo* ingredients :
Recipe: tomatoes (85.4%), olive oil (8.5%), bread (4.3%), vinegar (0.9%), salt (0.9%) and garlic (0.1%)

PRODUCTION STAGE (CORE)

INPUTS

Energy
Water
Auxiliary materials (cleaning products, etc.)
Packaging materials

Foreground system **PILOT PLANT:** 200 l·h^{-1}

- Washing of vegetables
- Grinding and sieving
- Mixing and 1st homogenisation
- Pre-heating
- 2nd Homogenisation
- Pasteurisation
- Cooling
- Packing

Cleaning In Place

SCALE-UP

INDUSTRY
Large scale: 4,000 l·h^{-1}
Medium scale 2: 12,000 l·h^{-1}

Foreground system

- Washing of vegetables
- Grinding, sieving and homogenization
- Degassing
- Pre-heating
- Pasteurisation
- Cooling
- Packing

Cleaning In Place

Wastewater treatment

Organic waste to landfill or to

OUTPUTS

Wastewater
Other indirect emissions

Pasteurised packed *salmorejo*

CASE STUDY: RESULTS

1. How does up-scaling affect the environmental impacts of RF-processing?

		“Gate to Gate”				“Farm to Factory Gate”
		Pilot	Medium Scale		Large Scale	Large Scale
		RF—Landfill	RF—Landfill	CT—Landfill	RF—Landfill	RF—Landfill
Climate change, default, excl. biogenic carbon (kg CO$_2$ eq.)	CCnB	$2.55 \cdot 10^{-1}$	$1.78 \cdot 10^{-1}$	$1.86 \cdot 10^{-1}$	$1.49 \cdot 10^{-1}$	$3.96 \cdot 10^{-1}$
Climate change, incl. biogenic carbon (kg CO$_2$ eq.)	CCB	$1.72 \cdot 10^{-1}$	$9.40 \cdot 10^{-2}$	$1.01 \cdot 10^{-1}$	$6.31 \cdot 10^{-2}$	$1.61 \cdot 10^{-1}$
Fine particulate matter formation (kg PM2.5 eq.)	FPM	$2.32 \cdot 10^{-4}$	$1.92 \cdot 10^{-4}$	$1.92 \cdot 10^{-4}$	$1.85 \cdot 10^{-4}$	$6.55 \cdot 10^{-4}$
Fossil depletion (kg oil eq.)	FD	$6.95 \cdot 10^{-2}$	$5.73 \cdot 10^{-2}$	$6.03 \cdot 10^{-2}$	$5.57 \cdot 10^{-2}$	$1.25 \cdot 10^{-1}$
Freshwater eutrophication (kg P eq.)	FWEU	$4.50 \cdot 10^{-5}$	$3.60 \cdot 10^{-5}$	$3.60 \cdot 10^{-5}$	$3.60 \cdot 10^{-5}$	$1.44 \cdot 10^{-4}$
Ionising radiation (kBq Co-60 eq. to air)	IR	$1.09 \cdot 10^{-2}$	$1.00 \cdot 10^{-2}$	$1.00 \cdot 10^{-2}$	$9.70 \cdot 10^{-3}$	$2.05 \cdot 10^{-2}$
Land use (Annual crop eq.·y)	LU	$8.90 \cdot 10^{-2}$	$8.80 \cdot 10^{-2}$	$8.80 \cdot 10^{-2}$	$8.80 \cdot 10^{-2}$	$4.08 \cdot 10^{-1}$
Marine eutrophication (kg N eq.)	MEU	$2.80 \cdot 10^{-5}$	$2.20 \cdot 10^{-5}$	$2.10 \cdot 10^{-5}$	$2.10 \cdot 10^{-5}$	$4.17 \cdot 10^{-4}$
Metal depletion (kg Cu eq.)	MD	$1.50 \cdot 10^{-3}$	$1.00 \cdot 10^{-3}$	$9.90 \cdot 10^{-4}$	$7.60 \cdot 10^{-4}$	$2.38 \cdot 10^{-3}$
Photochemical ozone formation, ecosystems (kg NO$_x$ eq.)	PHE	$4.30 \cdot 10^{-4}$	$3.60 \cdot 10^{-4}$	$3.60 \cdot 10^{-4}$	$3.50 \cdot 10^{-4}$	$1.39 \cdot 10^{-3}$
Photochemical ozone formation, human health (kg NO$_x$ eq.)	PHH	$4.10 \cdot 10^{-4}$	$3.40 \cdot 10^{-4}$	$3.40 \cdot 10^{-4}$	$3.30 \cdot 10^{-4}$	$1.36 \cdot 10^{-3}$
Stratospheric ozone depletion (kg CFC-11 eq.)	ODE	$7.20 \cdot 10^{-7}$	$3.00 \cdot 10^{-7}$	$3.00 \cdot 10^{-7}$	$2.90 \cdot 10^{-7}$	$1.85 \cdot 10^{-6}$
Terrestrial acidification (kg SO$_2$ eq.)	TA	$5.40 \cdot 10^{-4}$	$4.30 \cdot 10^{-4}$	$4.30 \cdot 10^{-4}$	$4.00 \cdot 10^{-4}$	$1.98 \cdot 10^{-3}$
Terrestrial ecotoxicity (kg 1,4-DB eq.)	TEC	$3.90 \cdot 10^{-1}$	$3.20 \cdot 10^{-1}$	$3.10 \cdot 10^{-1}$	$2.90 \cdot 10^{-1}$	$2.05 \cdot 10^{0}$
Ecotoxicity (CTUe)	ET	$6.30 \cdot 10^{2}$	$4.50 \cdot 10^{2}$	$4.50 \cdot 10^{2}$	$4.20 \cdot 10^{2}$	$1.92 \cdot 10^{3}$
Human toxicity, cancer (CTUh)	HTC	$1.04 \cdot 10^{-8}$	$8.80 \cdot 10^{-9}$	$8.70 \cdot 10^{-9}$	$8.50 \cdot 10^{-9}$	$2.48 \cdot 10^{-8}$
Human toxicity, non-canc. (CTUh)	HTnC	$5.24 \cdot 10^{-8}$	$2.90 \cdot 10^{-8}$	$2.90 \cdot 10^{-8}$	$2.70 \cdot 10^{-8}$	$1.86 \cdot 10^{-7}$
Water scarcity (m^3 world equiv.)	WSC	$3.97 \cdot 10^{-1}$	$1.10 \cdot 10^{-1}$	$1.30 \cdot 10^{-1}$	$9.00 \cdot 10^{-2}$	$2.28 \cdot 10^{0}$

- Impacts at the pilot scale are greater.
- Reasons: greater energy consumption (no heat recovery) and the change from an electric boiler to natural gas at the industrial scale.
- Main differences between pilot and medium scale in CCB (16% greater at pilot), MD (17%), and ODE (19%)
- Differences between medium and large scale are evident in CCnB (8%), CCB (17%), and MD (10%).

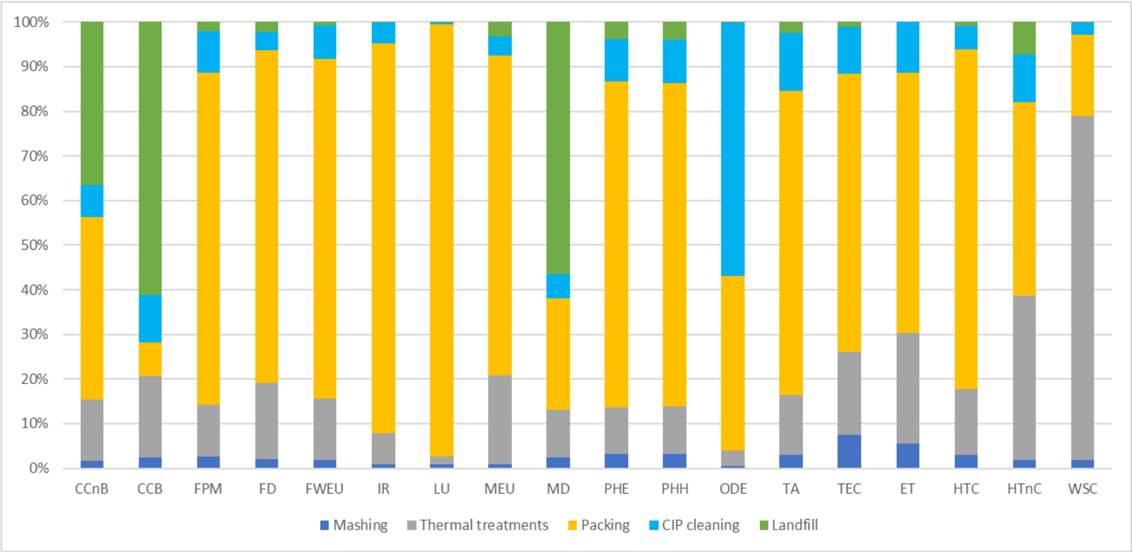
CASE STUDY: RESULTS

2. Are there relevant differences between RF and conventional pasteurization?

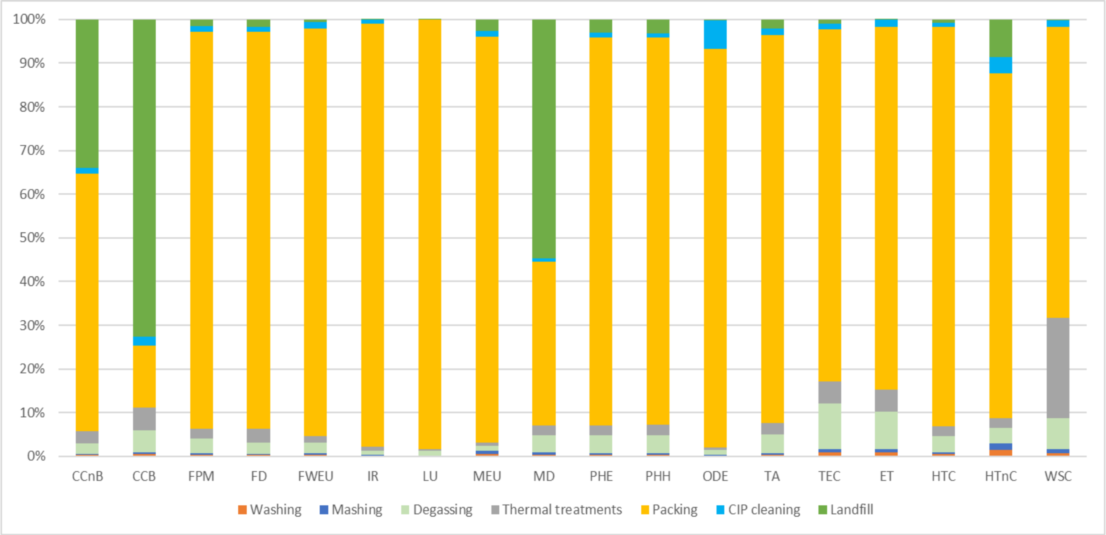
		"Gate to Gate"				"Farm to Factory Gate"
		Pilot	Medium Scale		Large Scale	Large Scale
		RF—Landfill	RF—Landfill	CT—Landfill	RF—Landfill	RF—Landfill
Climate change, default, excl. biogenic carbon (kg CO_2 eq.)	CCnB	$2.55\cdot10^{-1}$	$1.78\cdot10^{-1}$	$1.86\cdot10^{-1}$	$1.49\cdot10^{-1}$	$3.96\cdot10^{-1}$
Climate change, incl. biogenic carbon (kg CO_2 eq.)	CCB	$1.72\cdot10^{-1}$	$9.40\cdot10^{-2}$	$1.01\cdot10^{-1}$	$6.31\cdot10^{-2}$	$1.61\cdot10^{-1}$
Fine particulate matter formation (kg PM2.5 eq.)	FPM	$2.32\cdot10^{-4}$	$1.92\cdot10^{-4}$	$1.92\cdot10^{-4}$	$1.85\cdot10^{-4}$	$6.55\cdot10^{-4}$
Fossil depletion (kg oil eq.)	FD	$6.95\cdot10^{-2}$	$5.73\cdot10^{-2}$	$6.03\cdot 10^{-2}$	$5.57\cdot10^{-2}$	$1.25\cdot10^{-1}$
Freshwater eutrophication (kg P eq.)	FWEU	$4.50\cdot10^{-5}$	$3.60\cdot10^{-5}$	$3.60\cdot10^{-5}$	$3.60\cdot10^{-5}$	$1.44\cdot10^{-4}$
Ionising radiation (kBq Co-60 eq. to air)	IR	$1.09\cdot10^{-2}$	$1.00\cdot10^{-2}$	$1.00\cdot 10^{-2}$	$9.70\cdot10^{-3}$	$2.05\cdot10^{-2}$
Land use (Annual crop eq.·y)	LU	$8.90\cdot10^{-2}$	$8.80\cdot10^{-2}$	$8.80\cdot 10^{-2}$	$8.80\cdot10^{-2}$	$4.08\cdot10^{-1}$
Marine eutrophication (kg N eq.)	MEU	$2.80\cdot10^{-5}$	$2.20\cdot10^{-5}$	$2.10\cdot10^{-5}$	$2.10\cdot10^{-5}$	$4.17\cdot10^{-4}$
Metal depletion (kg Cu eq.)	MD	$1.50\cdot10^{-3}$	$1.00\cdot10^{-3}$	$9.90\cdot10^{-4}$	$7.60\cdot10^{-4}$	$2.38\cdot10^{-3}$
Photochemical ozone formation, ecosystems (kg NO_x eq.)	PHE	$4.30\cdot10^{-4}$	$3.60\cdot10^{-4}$	$3.60\cdot10^{-4}$	$3.50\cdot10^{-4}$	$1.39\cdot10^{-3}$
Photochemical ozone formation, human health (kg NO_x eq.)	PHH	$4.10\cdot10^{-4}$	$3.40\cdot10^{-4}$	$3.40\cdot10^{-4}$	$3.30\cdot10^{-4}$	$1.36\cdot10^{-3}$
Stratospheric ozone depletion (kg CFC-11 eq.)	ODE	$7.20\cdot10^{-7}$	$3.00\cdot10^{-7}$	$3.00\cdot10^{-7}$	$2.90\cdot10^{-7}$	$1.85\cdot10^{-6}$
Terrestrial acidification (kg SO_2 eq.)	TA	$5.40\cdot10^{-4}$	$4.30\cdot10^{-4}$	$4.30\cdot10^{-4}$	$4.00\cdot10^{-4}$	$1.98\cdot10^{-3}$
Terrestrial ecotoxicity (kg 1,4-DB eq.)	TEC	$3.90\cdot10^{-1}$	$3.20\cdot10^{-1}$	$3.10\cdot10^{-1}$	$2.90\cdot10^{-1}$	$2.05\cdot10^{0}$
Ecotoxicity (CTUe)	ET	$6.30\cdot10^{2}$	$4.50\cdot10^{2}$	$4.50\cdot10^{2}$	$4.20\cdot10^{2}$	$1.92\cdot10^{3}$
Human toxicity, cancer (CTUh)	HTC	$1.04\cdot10^{-8}$	$8.80\cdot10^{-9}$	$8.70\cdot10^{-9}$	$8.50\cdot10^{-9}$	$2.48\cdot10^{-8}$
Human toxicity, non-canc. (CTUh)	HTnC	$5.24\cdot10^{-8}$	$2.90\cdot10^{-8}$	$2.90\cdot10^{-8}$	$2.70\cdot10^{-8}$	$1.86\cdot10^{-7}$
Water scarcity (m³ world equiv.)	WSC	$3.97\cdot10^{-1}$	$1.10\cdot10^{-1}$	$1.30\cdot10^{-1}$	$9.00\cdot10^{-2}$	$2.28\cdot10^{0}$

- Minor differences between pasteurization technologies
- RF technology substitutes part of the thermal treatment, not preheating, made mainly by recovering the heat of the pasteurized product.

ANÁLISIS Y SIMULACIÓN
DE PROCESOS AGROALIMENTARIOS



Contribution analysis pilot scale using RF pasteurization, “gate-to-gate” system boundaries



Contribution analysis medium scale using RF pasteurization, “gate-to-gate” system boundaries

3. Which unit processes and life-cycle stages most contribute to impacts?

RF-Pilot scale:

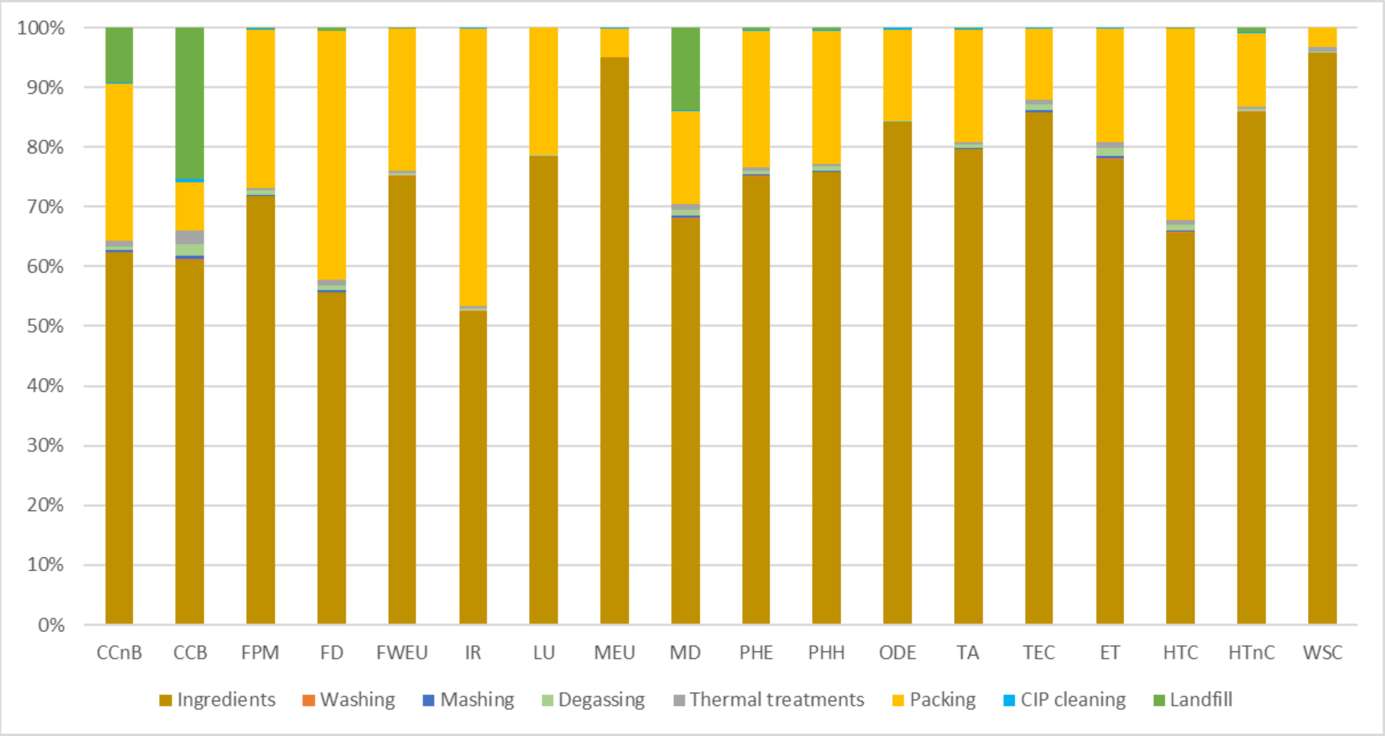
- packing (>24%, 97% in LU)
- thermal treatments (from 3% LU to 78% for WSC)
- organic waste landfill (39% CCnB, 66% CCB, 54% MD)
- CIP (56% ODE)

RF-Industrial scale:

- packing >60%, except CCB (8%), WSC (18%), and MD (25%)
- organic waste landfill CCnB (34% at medium and 24% at large scale), CCB (71% at medium and 65% at large scale), and MD (54% at medium and 43% at large scale).

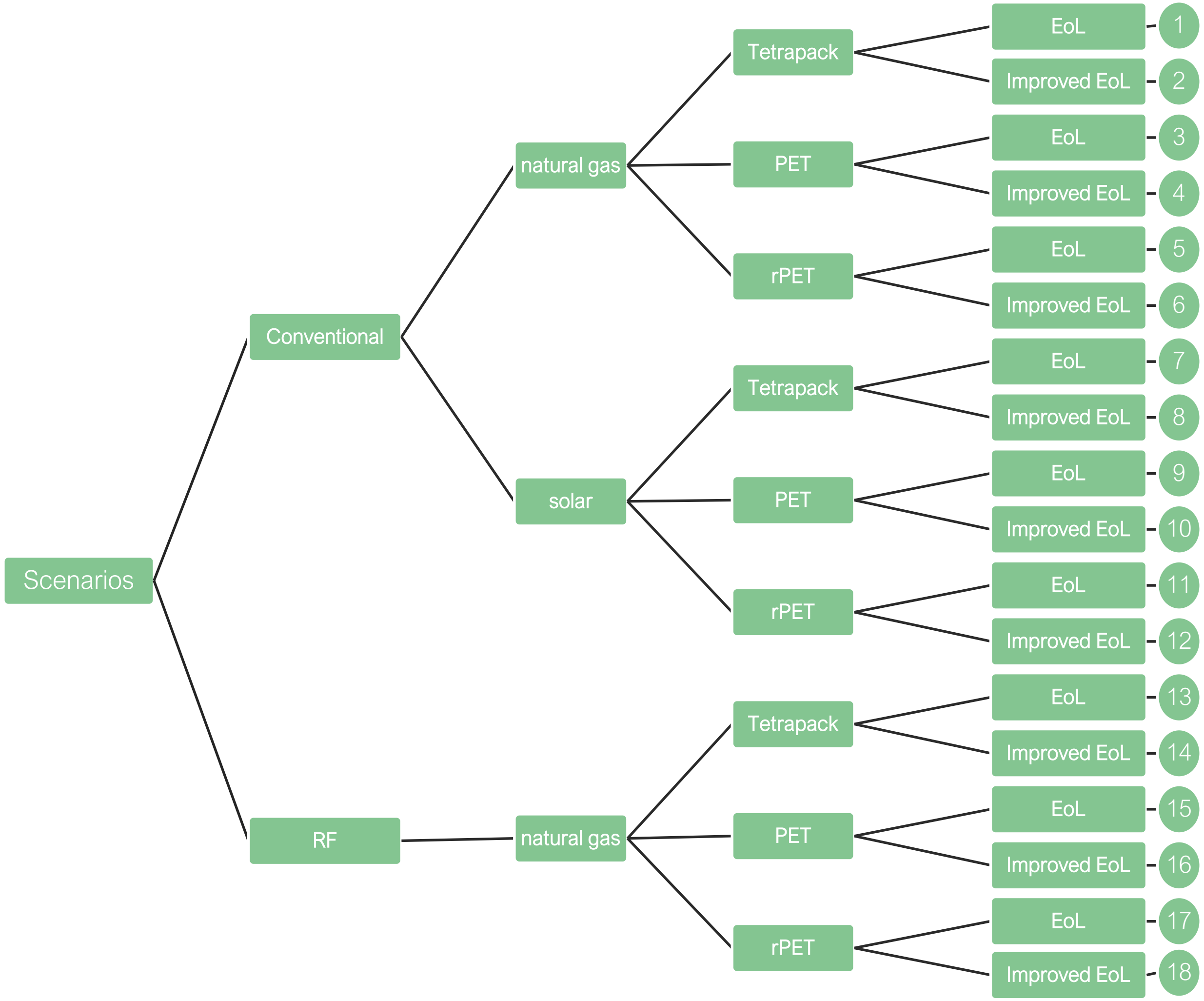
UPV

4. How relevant is processing in the *salmorejo* life cycle? and how can its impacts be reduced?

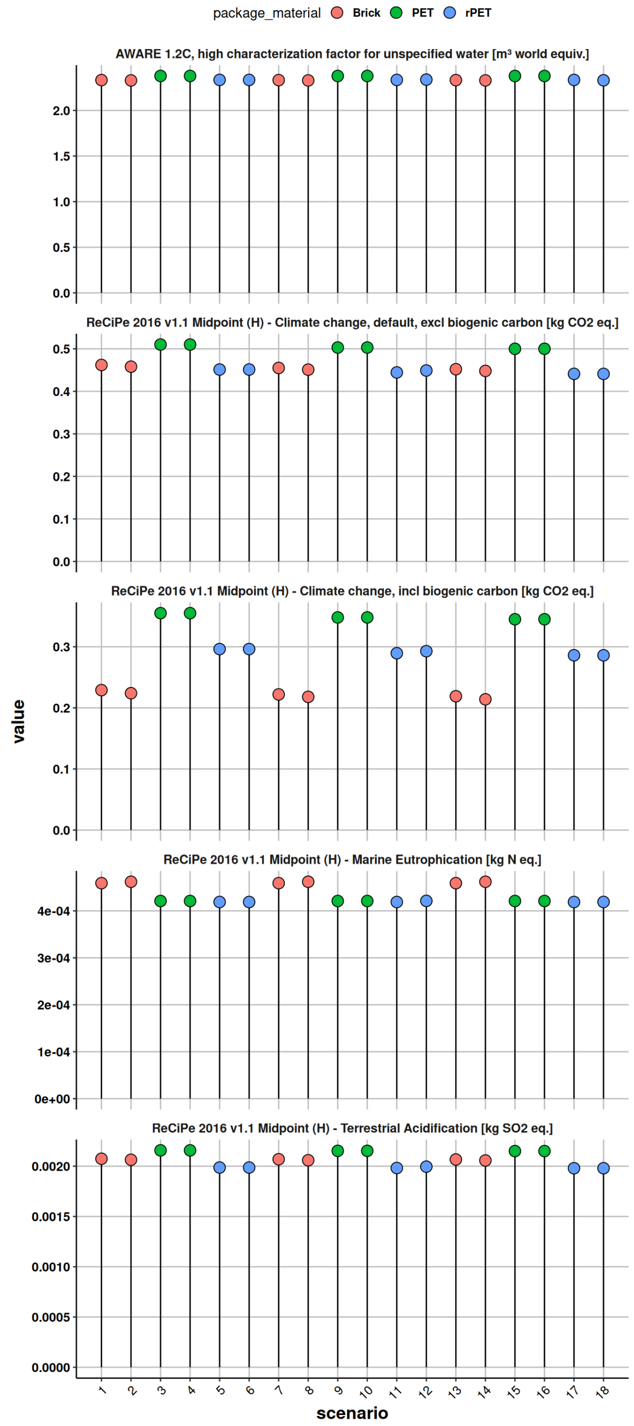


Ingredients, particularly tomatoes, make the most significant contribution to the total impact in every category, ahead of packaging and landfill.

4. How relevant is processing in the *salmorejo* life cycle? and how can its impacts be reduced?



- Scenarios
  - Conventional
    - natural gas
      - Tetrapack
        - EoL – 1
        - Improved EoL – 2
      - PET
        - EoL – 3
        - Improved EoL – 4
      - rPET
        - EoL – 5
        - Improved EoL – 6
    - solar
      - Tetrapack
        - EoL – 7
        - Improved EoL – 8
      - PET
        - EoL – 9
        - Improved EoL – 10
      - rPET
        - EoL – 11
        - Improved EoL – 12
  - RF
    - natural gas
      - Tetrapack
        - EoL – 13
        - Improved EoL – 14
      - PET
        - EoL – 15
        - Improved EoL – 16
      - rPET
        - EoL – 17
        - Improved EoL – 18



ANÁLISIS Y SIMULACIÓN
DE PROCESOS AGROALIMENTARIOS

SOME INSIGHTS

- Critical issues in prospective LCA:
  - Upscaling
  - Temporal background changes
  - Scenario analysis
- Integrating LCA and LCC useful to choose the best product design
- The results of prospective LCAs have, despite the uncertainties, a great value for decision makers and the developers of new products.

Uncertainty

ANÁLISIS Y SIMULACIÓN

Thanks

Project funded by the Spanish Ministry of Science, Innovation and Universities project RF-SUSVEG (RTI2018-098052-R-C31)

UPV