Food waste valorisation in food product design
June, 6th 2025

Co-funded by the European Union

Challenge based lecture

Session 1

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Food waste: from what, what, what for and how: current and future sustainable strategies for valorisation

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This work has been developed under the ERASMUS-EDU-2022-PI-FORWARD Project “*Glocal Ecosystems and Expanded Knowledge for green skills and capability in the Food Sector*” (**G4F**) - Project n° 101087203.
It is credited to the G4F Consortium.

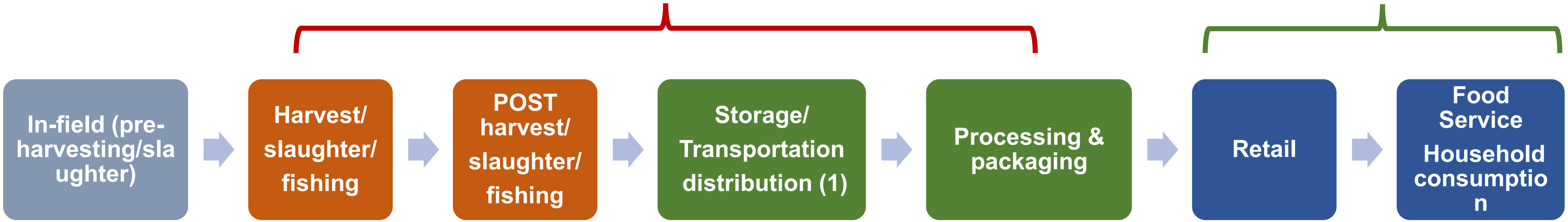
Food waste: from what and what

Food loss and waste (FLW)

Definitions and boundaries in the supply chain

FOOD LOSS
Decrease in quantity or quality of food resulting from decisions and actions by food suppliers in the chain, excluding retail, food service providers and consumers

FOOD WASTE
Decrease in quantity or quality of food resulting from decisions and actions by retailer, food service and consumers



Source: FAO, State of Food and Agriculture, 2019

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Food loss and waste

Definitions and boundaries in the supply chain

EU definitions

FOOD LOSS-FL : **any food that is discarded, incinerated or otherwise disposed of along the food supply chain** from harvest/slaughter/catch up to, but excluding, the retail level, and is not used for any other productive use, such as animal feed or seed.

FOOD WASTE-FW: food that **is discarded at retailers, food service providers and consumers level**.
Food is wasted in many ways, e.g.

- **Fresh produce** that deviates from what is considered optimal (e.g. size, shape or colour) and is removed during sorting actions
- Foods discarded by retailers or consumers close to or beyond the best before date.
- **Unused or leftover food** that is thrown out from households or restaurants.

Moreover: FW is discarded food and its **associated inedible parts** (such as bones or fruit cores).
It occurs at all **stages of the food supply chain, from farm to fork.**
However, the largest share is generated at consumption, which is a key area of focus for food waste prevention programmes.

https://food.ec.europa.eu/food-safety/food-waste/frequently-asked-questions-reducing-food-waste-eu_en

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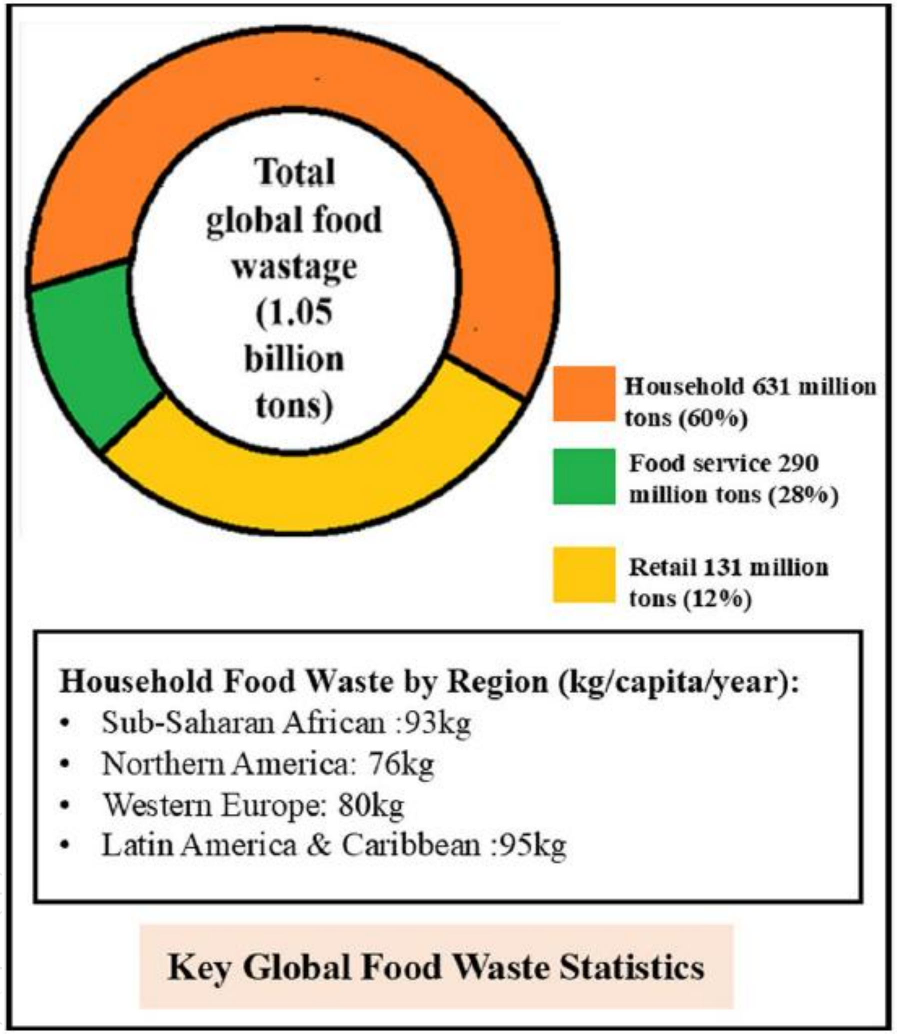
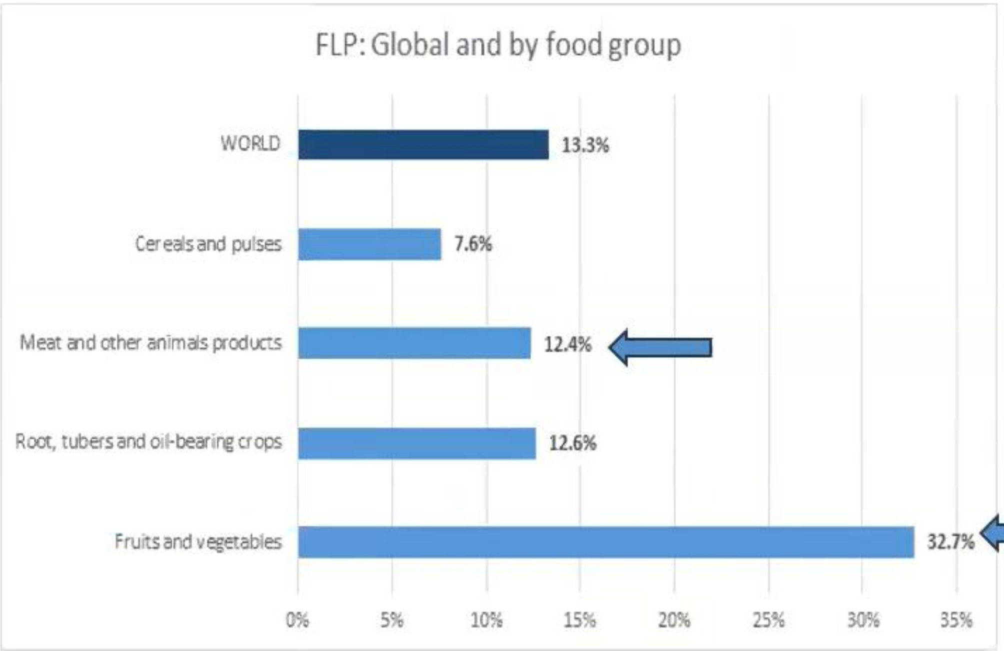
FLW statistics
World





Source: FAO, 2023

13 % of food is lost in the supply chain, from after harvest and prior to reaching retail shelves (2021) (FAI 2023)

19 % food is wasted **in household, services and retail (UNEP, 2024)**

→ 60% household

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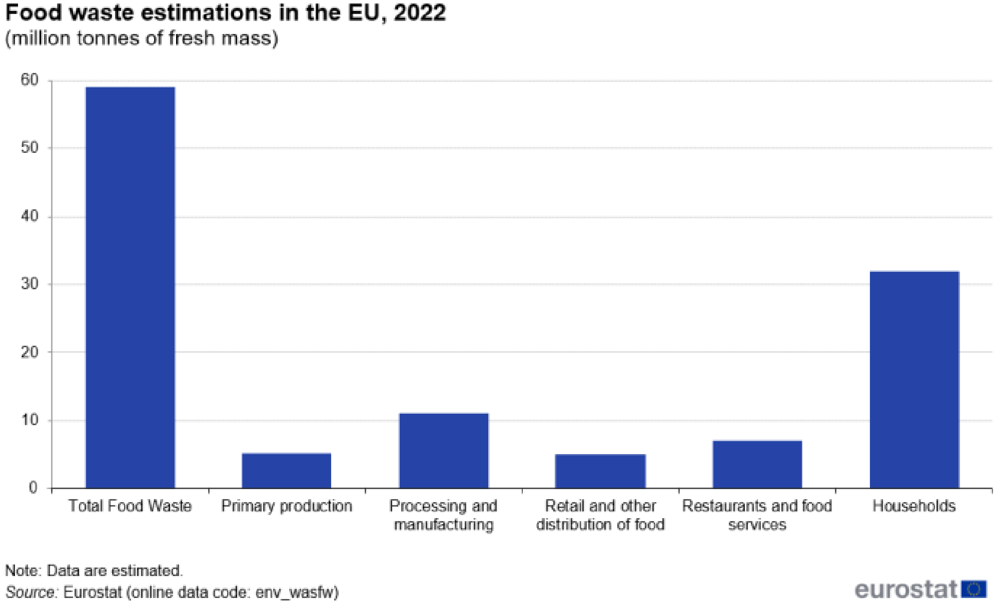
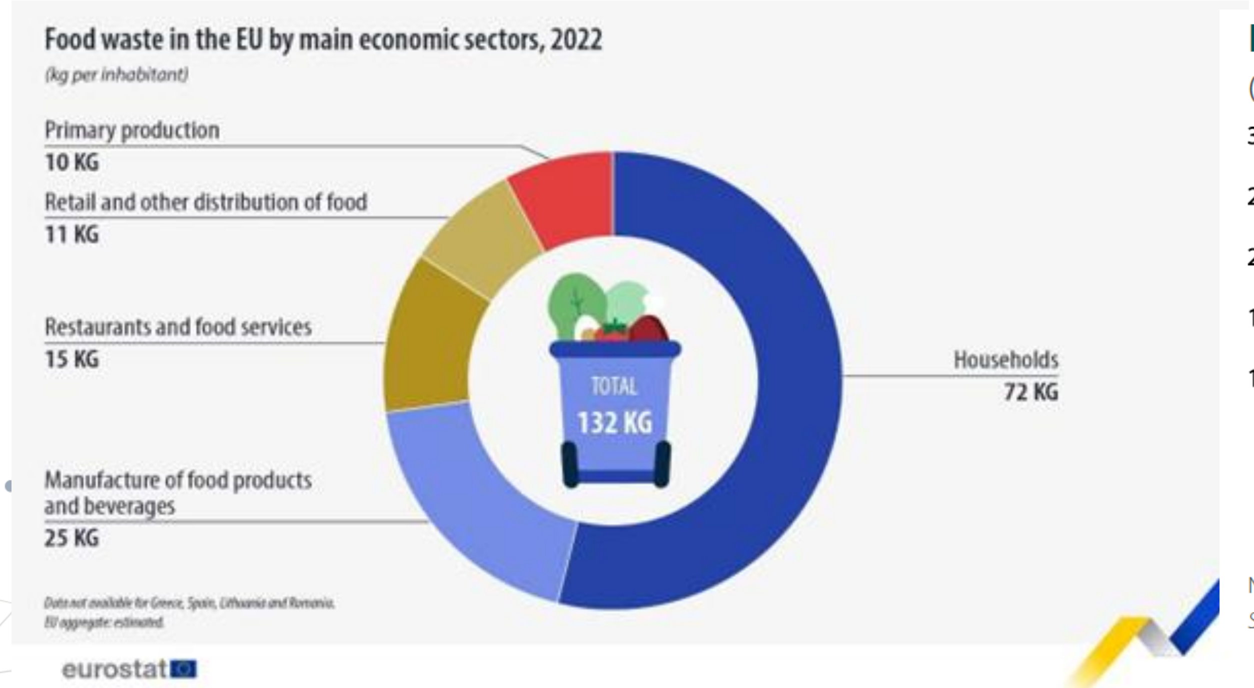
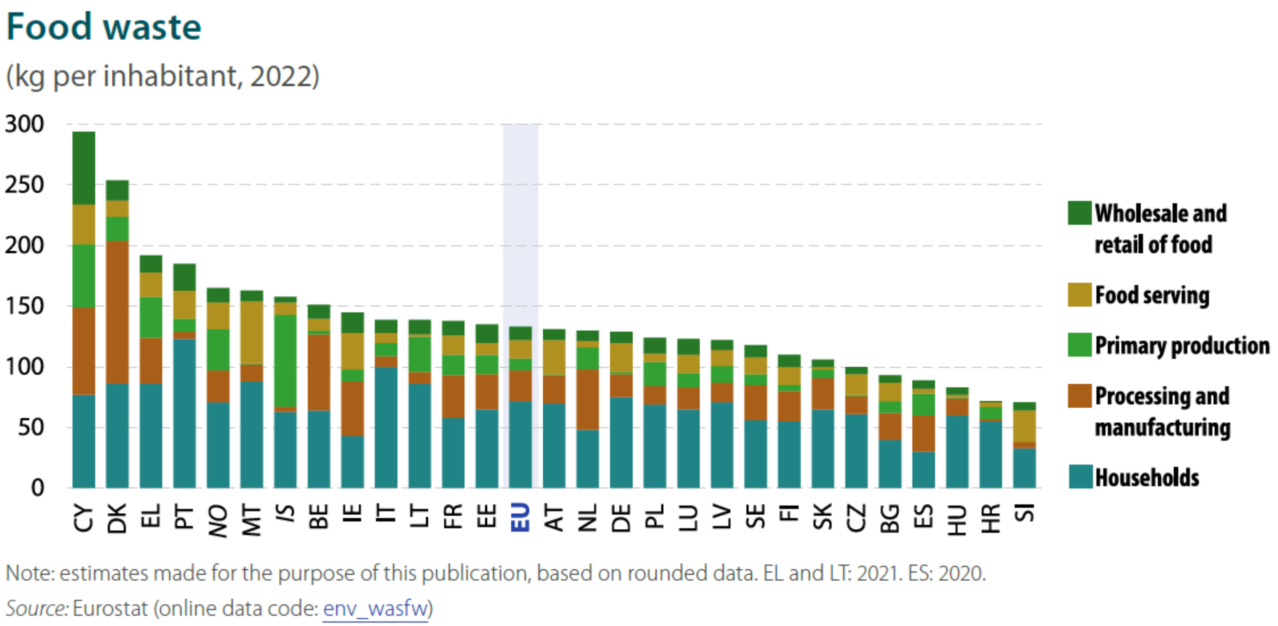
FLW statistics
Europe



Please Note

The total amount of food waste represents ca. 10% of the total food supply





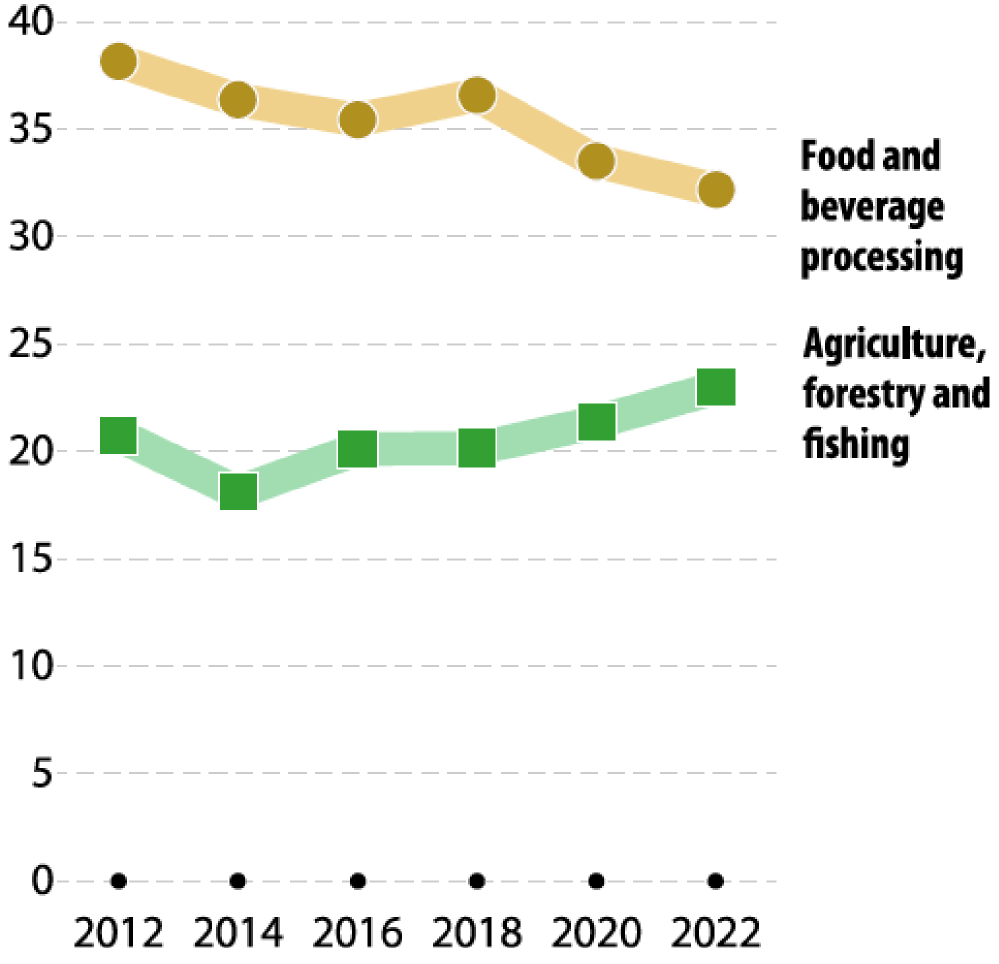
https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Food_waste_and_food_waste_prevention_-_estimates

FLW statistics
Europe

2022, EU:
Agriculture, forestry and fishing and the processing of food, beverage and tobacco: 55.1 million tonnes wastes, corresponding to a 2.7% of all waste from productive activities.

Between 2012 and 2022
Waste generated by food, beverage and tobacco processing: decrease by 15.7%;.
Waste from agriculture, forestry and fishing: increase by 10.6%

(million tonnes, EU, 2012–22)



Source: Eurostat (online data code: env_wasgen)

Food waste: why?

Food loss and waste

Causes of losses and wastes in food supply chains

Limitations of agricultural practices
Transport and storage infrastructure
Climate and environmental issues
Production surplus
Regulations and standards

Limitations/issues in the distribution chains
Orders and stock errors
Packaging and product damage
Marketing and selling strategies
International custom issues
Regulations

FOOD LOSS

FOOD WASTE

Limitations/issues in the production processes
Not optimised processes
Packaging and labelling mistakes
…

Excessive purchase
Overportioning
Difficulties in labels understanding
Storage mistakes
Lack of care
…

Food loss and waste

Impact

SUSTAINABILITY CIRCULAR BIOECONOMY

ETICAL AND SOCIETAL
Food waste → → no accessibility (food security)
Food surplus → → Malnutrition
Nutrients wastage → → lack of nutrients

FOOD LOSS

FOOD WASTE

ECONOMIC
Cost and value of the wasted food
Costs-opportunities of farming/land

ENVIRONMENT
Greenhouse gases
Water wastage
Environmental degradation
Energetic costs

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Food loss and waste

EU and International policies

2015, UN Agenda 2030

Food 2030 (EC, 2016)
Research and innovation policy to transform food systems and ensure everyone has enough affordable, nutritious food to lead a healthy life.

The Green Deal (EC, 2019)
Policy initiatives package to set the path to a **green transition up to** climate neutrality by 2050.
It includes the **"Farm to fork**" **strategy,** aiming to make food systems fair, healthy and environmentally-friendly.
Reducing food loss and waste is an integral part of **the Farm to Fork Strategy** action plan.

Food loss and waste

EU and International policies

Circular bioeconomy: new economic model that emphasizes the use of renewable natural capital and focuses on minimizing waste, replacing the wide range of non-renewable, fossil-based products currently in use.

- recovery and valorization of waste
- upcycling strategies

https://doi.org/10.1038/s43247-024-01663-6 Perspective

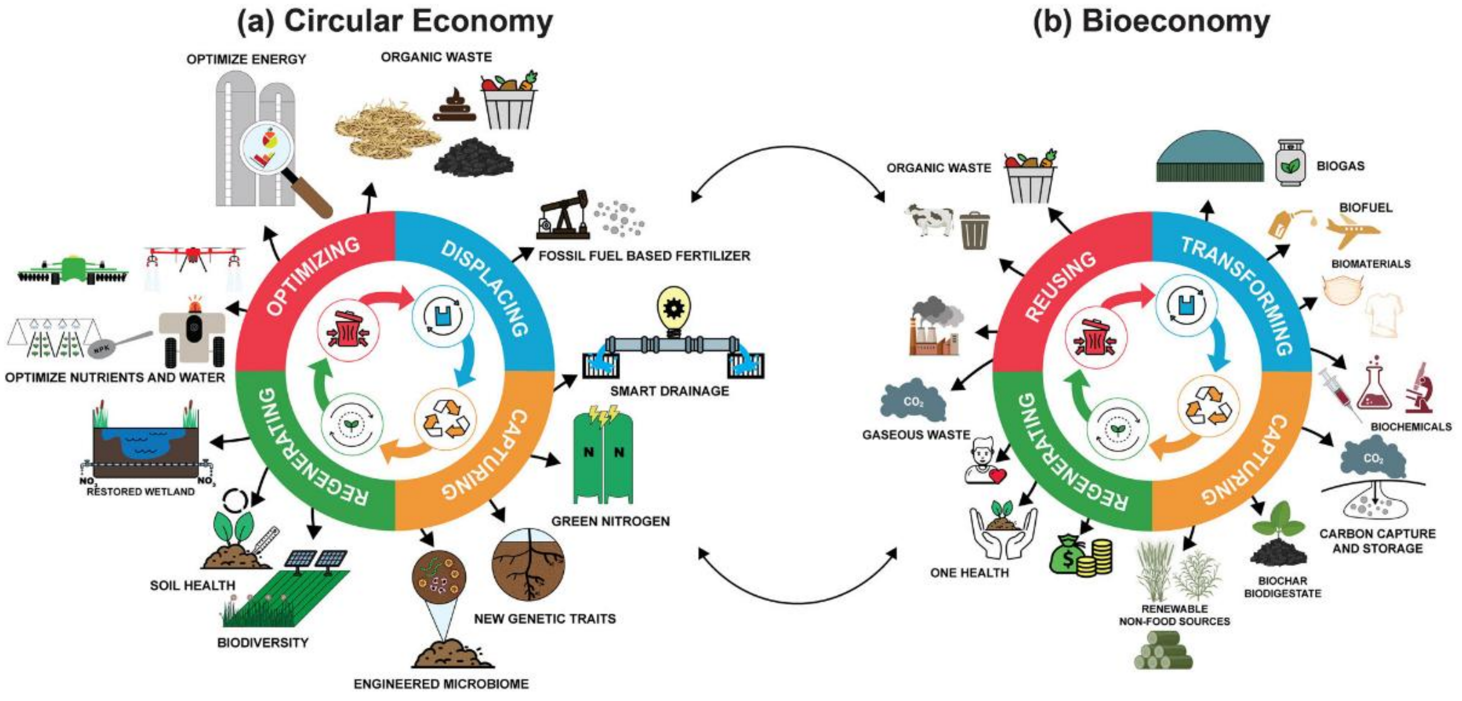
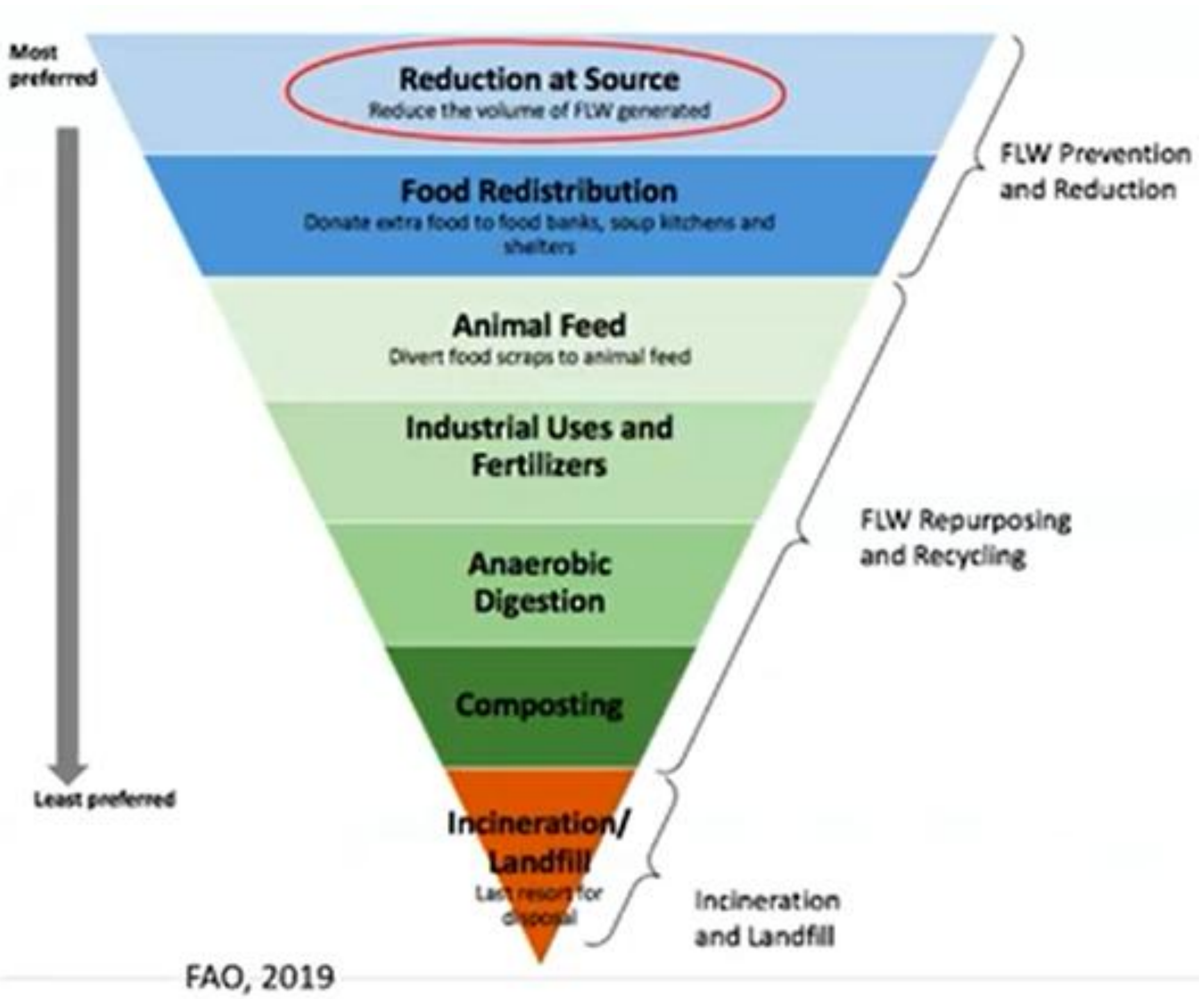


Fig. 1 | Multiple pathways to a circular bioeconomy. a represents multiple pathways to reduce, recyle and reuse waste in a circular economy; **b** represents multiple pathways to produce inputs, food and energy products in a bioeconomy. Together, the two panels show the interconnections among the pathways to reduce, recycle and reuse waste and to convert unavoidable waste and other biological resources to bioproducts that displace fossil fuels.

Food loss and waste: prioritization of actions



Food-use-not waste hierarchy:

- top: PREVENTION AND REDUCTION of FW at source; it follows: recovery and redistribution of surplus food
- Food waste, surplus food and by product can be still upcycled into food or valuable products or recycled through composting
- Bottom: DISPOSAL!

Awareness raising and EDUCATION of consumers is crucial for preventing food waste

What about at "supply chain" level?

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Food waste valorization: how and what for?

Food loss and waste

Causes of losses and wastes in food supply chains

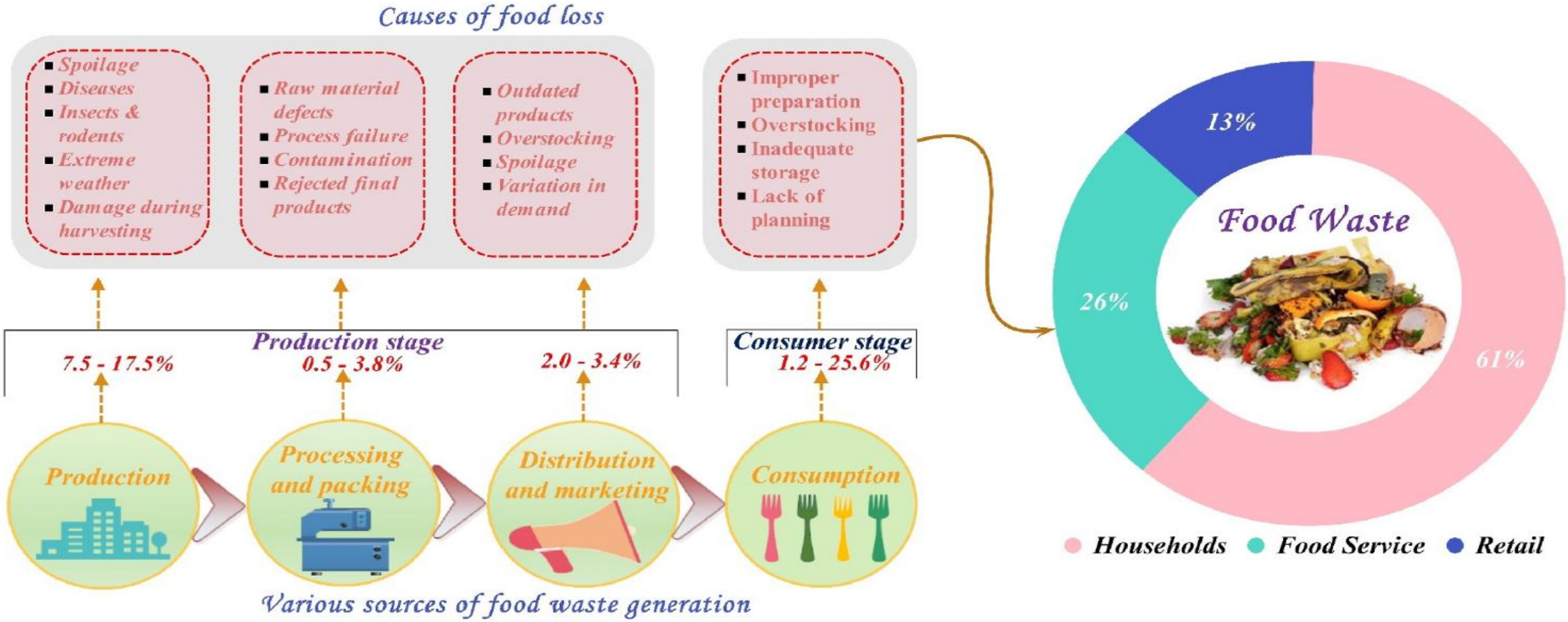


Fig. 1. Sources and generation of food waste from various sector (UNEP, 2021).
Source: Di Fraia et al., 2024

Food loss and waste

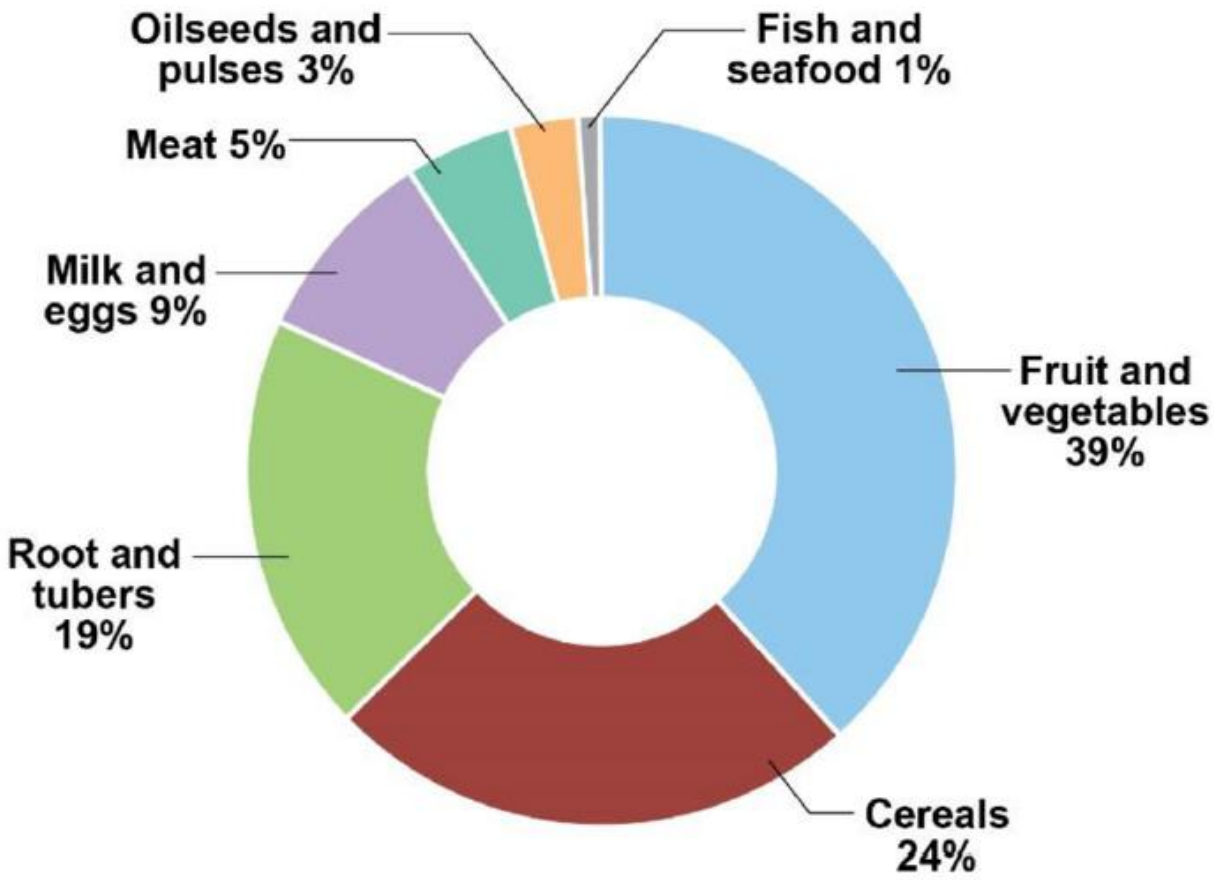
Causes of losses and wastes in food supply chains

- Nutrients (proteins, carbohydrates, ….)
- Healthy components (vitamines, salts, healthy fatty acids, etc.…)
- Enzymes
- Secondary metabolites with technological performances
- (colouringa gents, emulsifiers, etc..)

Fig. 1. Sources and generation of food waste from various sector (UNEP, 2021).
Source: Di Fraia et al., 2024

Food loss and waste

What?



Share of various global food waste.
Source: Roy et al., 2023

Fruits and vegetables are the major contributors to the total FW in different jurisdictions followed by cereals, root and tubers, milk, meat, and others.

However, the generation of FW depends on the types of food, processing stages, and food supply chains, as well as the jurisdictions.

UNEP, 2024

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Food loss and waste

The complexity of FLW in processing (prior to retail)

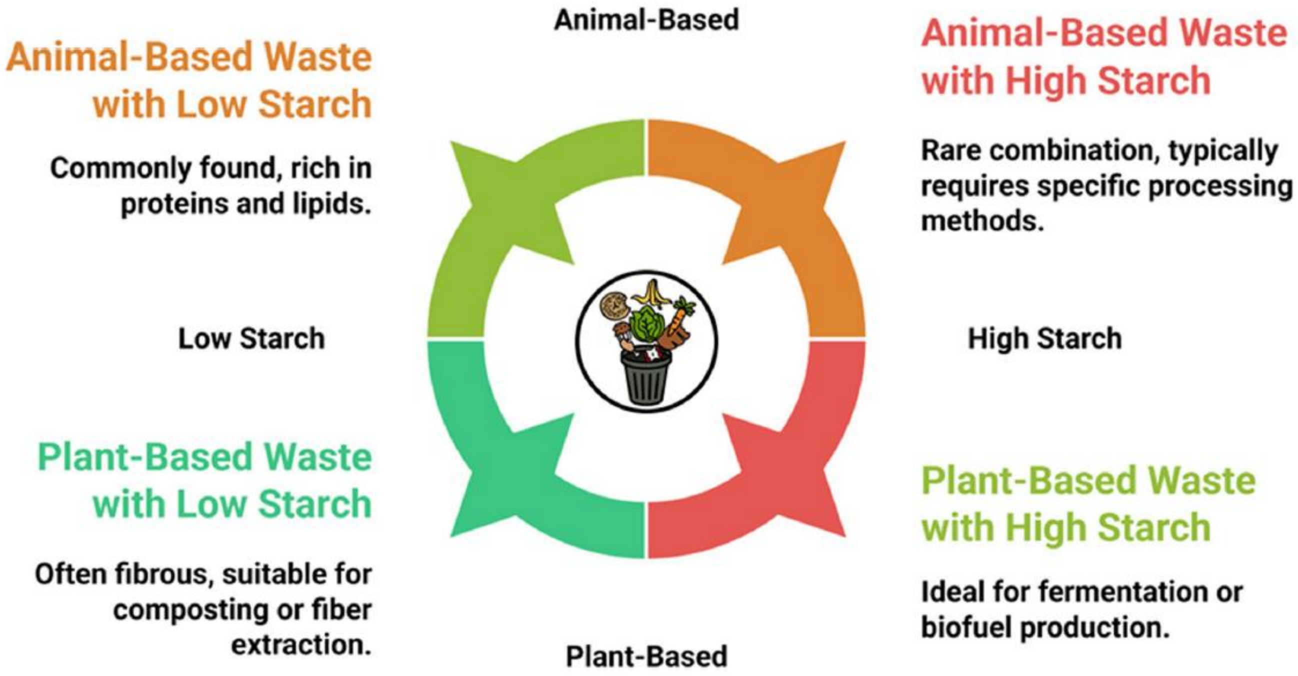

Fig. 2 Categories of food waste

Dhimal et al., 2025

This classification doesn't apply to:

- Processed products
- Sugar-containing products
- Complex food formulated products

It doesn't highlight:

- the potential nutritional and health value of the side-streams
- The suitability for recycling, recovery, valorisation

UNEP, 2024

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Food loss and waste

The complexity of FLW in processing (prior to retail)

Credits: www.un.org

- Quality vary at different processing steps (initial *vs.* end)
- Single ingredient vs. formulated products
- Formulated foods (complex recipies, multidomains,…)
  - complex composition
  - composition may vary
  - difficult to extract/separate individual compounds
- Packed vs. unpacked
- Wasted packaging?

UNEP, 2024

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Food loss and waste: valorization paths

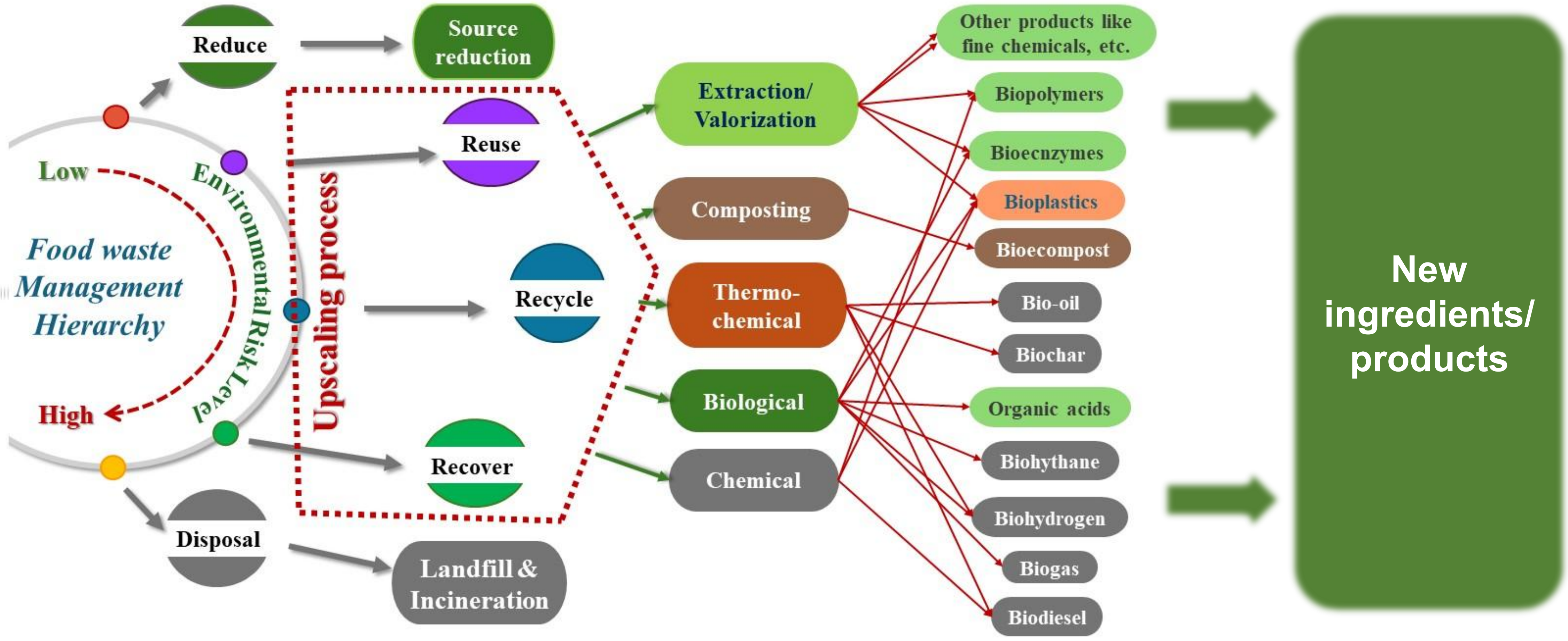

Fig. 2. Food waste management and upscaling process for biofuels and value-added products generation.

Modified from Roy et al., 2023

Recovery paths (bio-refinery) for FLW resources

Challenges

- **COSTS**
  - Each step has to consider plants, infrastructure, staff costs (and capabilities
  - CONVENTIONAL < costs than EMERGING
- **SAFETY**
  - Presence of contaminants (initial raw materials)
  - New generated compounds (e.g. Maillard reactio products, et.)
  - Legislation (food-grade, novel foods)
- **TECHNOLOGIES**
  - Availability
  - Optimisation
- **STAFF**
  - Knowledge, skills, capabilities

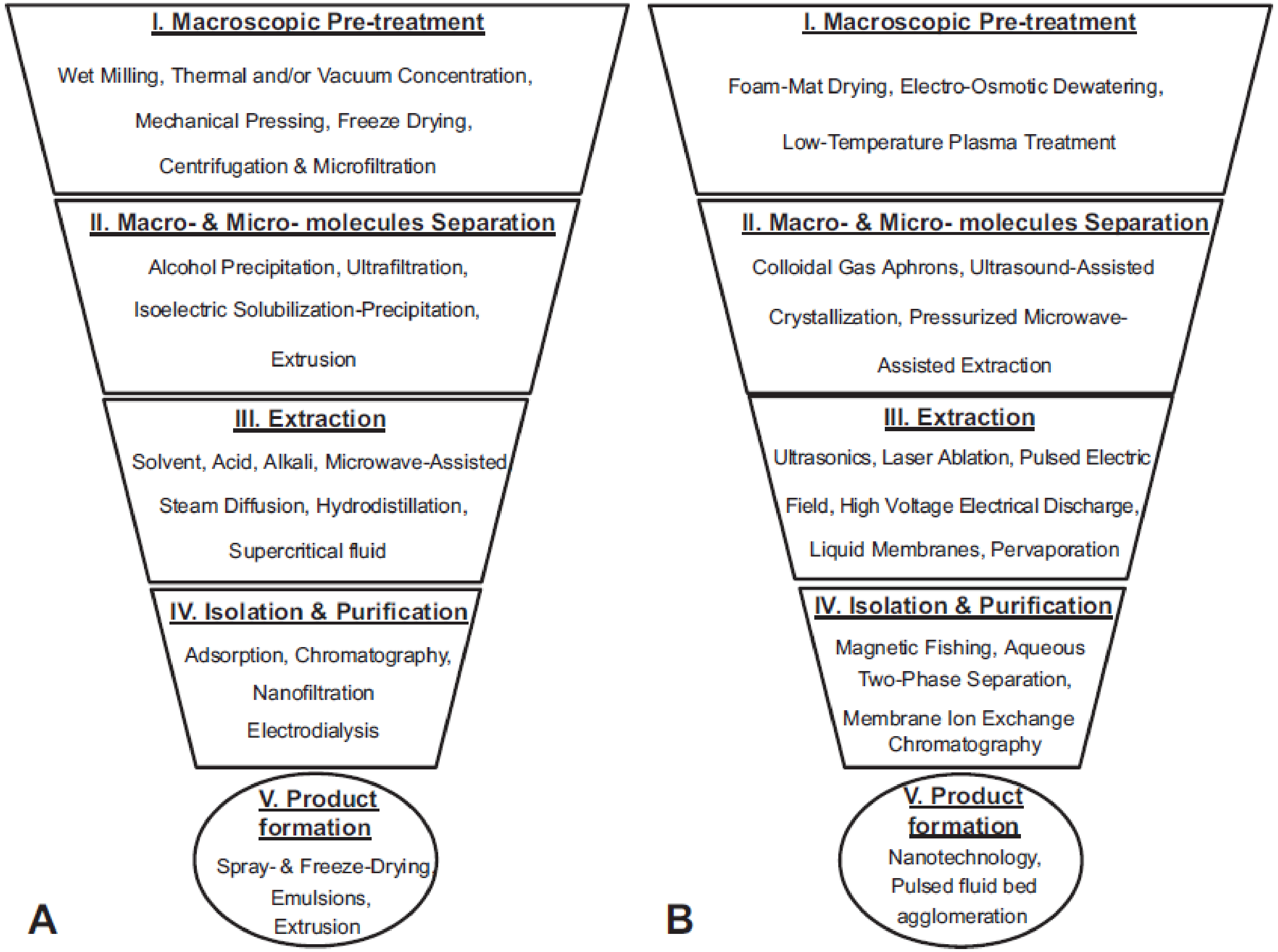

Fig. 1. Recovery stages of high-added value components from food wastes: (A) established and (B) emerging technologies.
Source: Galanakis , 2012

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Recovery paths (bio-refinery) for FLW resources

Strategy	Critical points	To be studied/developed/implemented
Reduce	….?	….
Upcycling: reuse (side-streams, waste, etc..)	• Quality and safety of the initial product • Suitability for the scope (individual raw material vs. formulated product)	• Understanding the technological performances • Definition of initial and final quality parameters • Identification and optimisation of technologies and/or formulations for the re-use (if needed) • Definition limits of the use
Up-cycling: recovery (biorefinery approaches)	• Quality and safety of the initial product • Costs	• Identification and optimisation of technologies • Understanding the technological performances of the biomolecules and process efficiency • Stabilisation technologies (e.g. microencapsulation)

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Food waste valorization: examples

1. Duynie

***Upcycled, plant-based, fibre rich, versatile and high in protein* (DuyGrain®)**
Obtained from Brewers' Spent Grains, co-product of the beer brewery industry; it mainly consists of the outside and protein parts of the barley.

Carrots powder: from carrots from the food industry, co-product released during the processing of food grade carrots.
Made of: off-sized shapes or top and bottom pieces of carrots after washing or steam peeling
Sustainability savings on carbon footprint, water footprint and land use compared with conventional alternatives.

Potatoes starch
Obtained from off-sizes shapes EU, no-GMO potatoes
Suitable as thickener, structuring, etc…

https://www.duynie.com/en/food/products/

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2. Sweets Factory & University of Teramo (Reversed Incubator, www.askfood.eu)

askfood Reversed Incubator

Company challenge:
Recovery of 2 by-products of of patisserie and bakery by-products:
- caramellised ground almonds
- meringue powder

Daily production, only partly upcycled
Issues: high presence of sugar and caramel (almonds)

Solution 1:
Formulation of a new dairy-dessert cream, high protein)
- cheesecake, filler for chilled pastries, croissant

Solution 2:
Re-formulation of a typical Italian cookie (nugat) made of the upcycled products

Thank you

www.geek4food.com

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Content Part 2

Session 2

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Technological functionalities of food waste for green ingredients design

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This work has been developed under the ERASMUS-EDU-2022-PI-FORWARD Project "*Glocal Ecosystems and Expanded Knowledge for green skills and capability in the Food Sector*" (**G4F**) - Project n° 101087203.
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'food ingredient' (definition)

any substance, including additives, used during the production of food, and present in the final product, in an unaltered or altered form.

Quality and techno-functional properties of ingredients

Each ingredient/ (food, bio-) component may play a major role in determining the quality of the final product, i.e. it is characterised by a specific "functionality"

- nutritional
- technological
- sensorial
- health
- stability, ...

“techno-functionality» or technological functionality

“…***performing or being able to perform a function***…

...
“each property of a food or food ingredient, excluded the nutritional ones, that influences its use and that is brought about from **how the different food components interact among them and/or the other components in the system.**»
(Mangino, 1984)

The **non-nutritional** characteristics of ingredients that influence their use and behavior during food processing and preparation.
These properties are crucial for creating specific food textures, viscosities, and structures and affect sensory acceptability and stability

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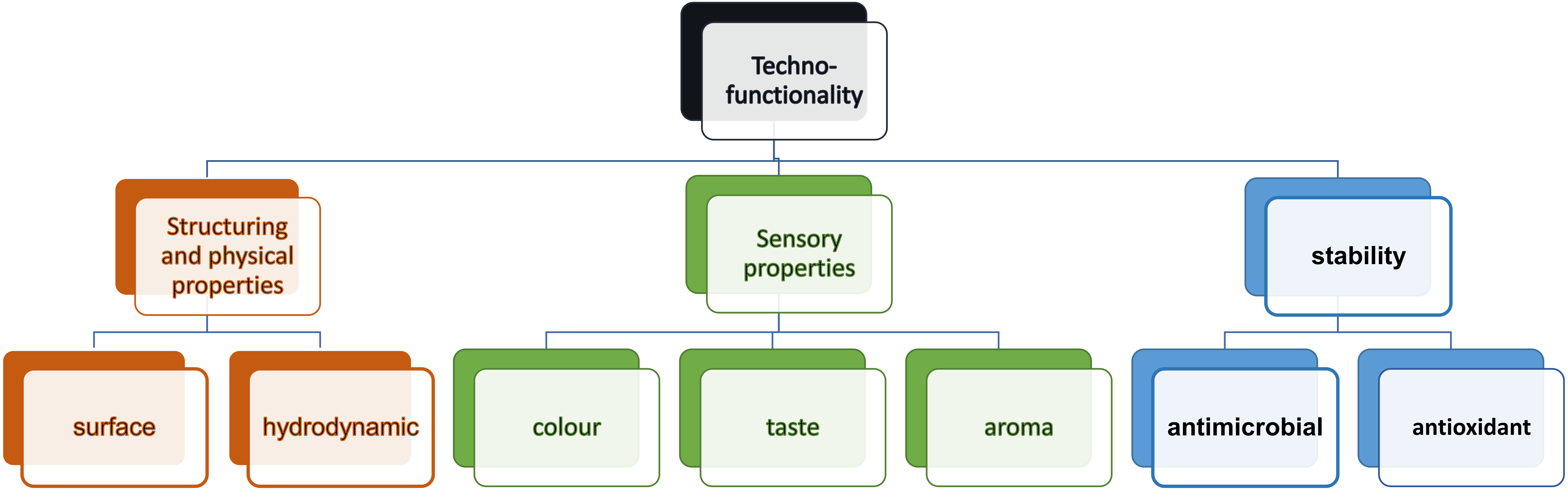


surface – e.g. Solubility, Wettability, Emulsying, Foaming …

hydrodynamic – e.g. Viscosity, Thickening, Film forming, gelling …

colour – Colour …

taste – e.g. Sweeteness, Salting, Bitterness, Sourness, Umani

aroma – Odorous compounds

Pittia, 2025

Factors affecting technological functionality (TF) of biomolecules

INTRINSIC FACTORS

Biomolecules properties

Chemical properties
Structure
Polarity and charge
….

EXTERNAL FACTORS

Matrix/system properties

Chemical and physico-chemical properties:
composition
pH, aw,
Ionic force
…

Environmental conditions

Temperature
Pressure
Light
….

Modification (e.g. denaturation, phase/ state transitions, ..)

Interactions/ reactions

FOOD QUALITY & STABILITY

TF of food biomolecules

Techno-functionality

Structuring and physical properties

surface

Solubility
Wettability
Emulsying
Foaming
Gelling
…

hydrodynamic

Viscosity
Thickening
Film forming
…

To structure a food (or a beverage) we need:

- Components with **structuring abilities**
- Processes and processing conditions **inducing structuring**

Surface: related to the ability to contribute **in developing structures** based on their "surface" features (polarity/apolarity, charges, etc..) and extrinsic factors

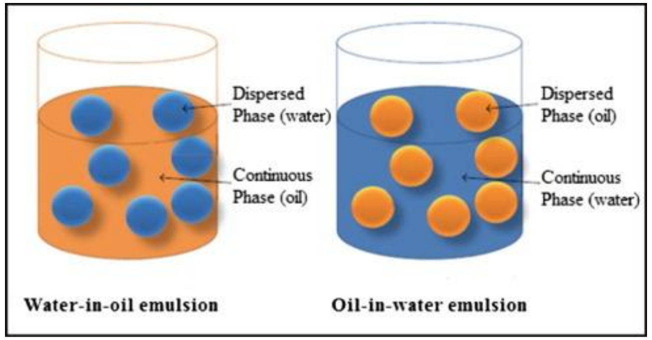
- by interacting with other molecules of the same type in the system and/or

- by allowing the interaction of other molecules and/or phases (e.g. emulsifying abilities)

Hydrodynamic: properties related to the **behavior of the biomolecule/ingredient in fluids** (e.g. water) ….thickening, stabilisers, etc…

TF of food biomolecules

Emulsions ⟵ Food structuring elements ⟶ Foams




sponge cake

Properties

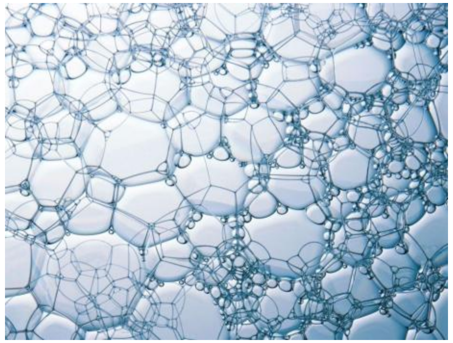
- Amphiphilicity
- Ability to form a stable **interface** between the two immiscible phases

Oil-water

Air-water

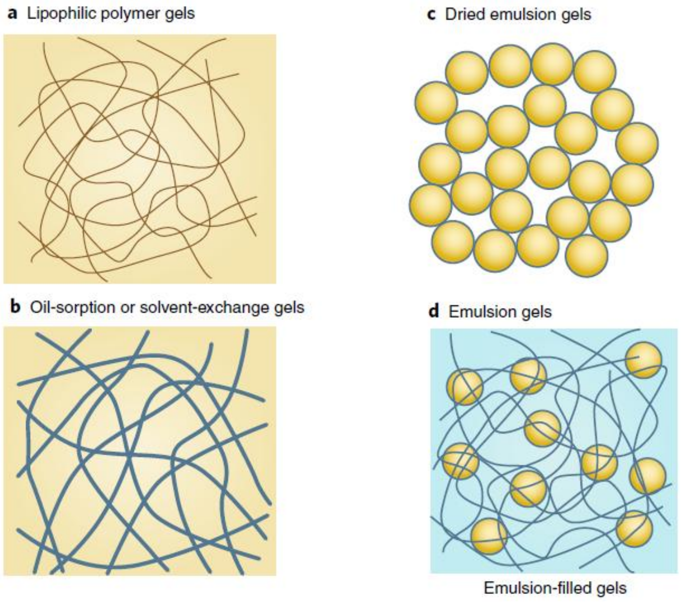
- Mono-, di-glycerides (E-number)
- Phospholipids (e.g. lecitin)
- Proteins (milk, whey, etc….)

Potential presence in food waste and side-streams



TF of food biomolecules

Gels ← Food structuring elements



Source: Cao & Mezzenga, 2020

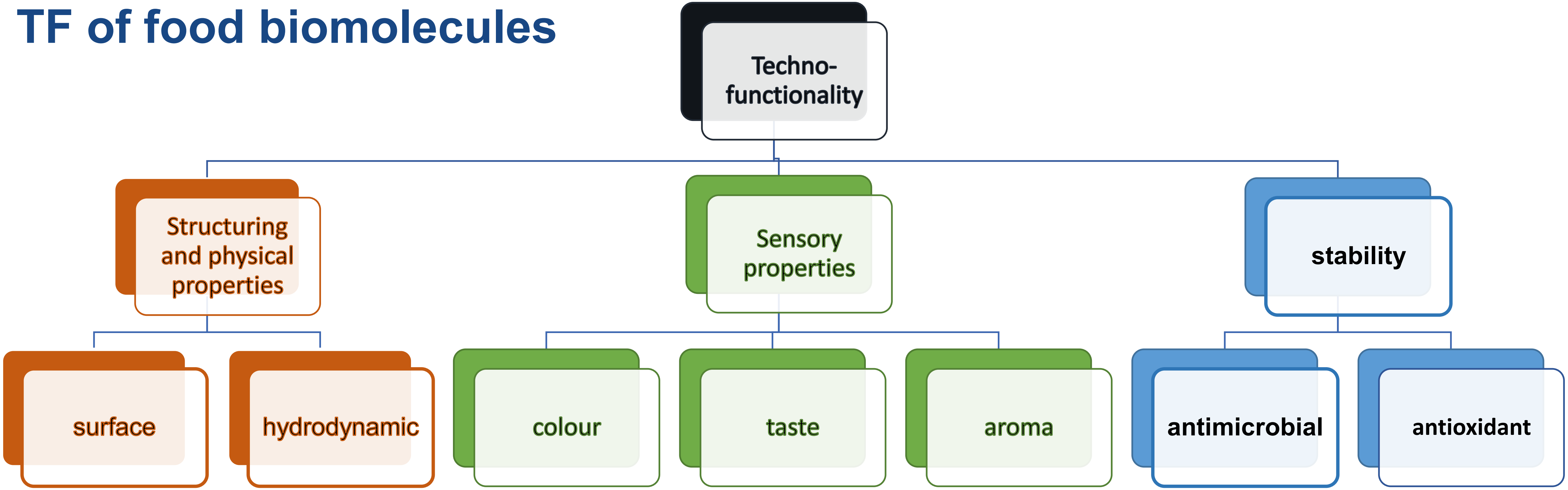
Compounds able to generate gel systems:

- proteins
- carbohydrates and polysaccharides (starch, pectines)
- hydrocolloids

Potential presence in food waste and side-streams

Examples of real gelled systems: jellies, jams, custard dessert, mortadella,….

TF of food biomolecules



e.g.
Solubility
Wettability
Emulsying
Foaming
…

e.g.
Viscosity
Thickening
Film forming
gelling
…

Colour
…

e.g.
Sweeteness
Salting
Bitterness
Sourness
Umani

Odorous compounds

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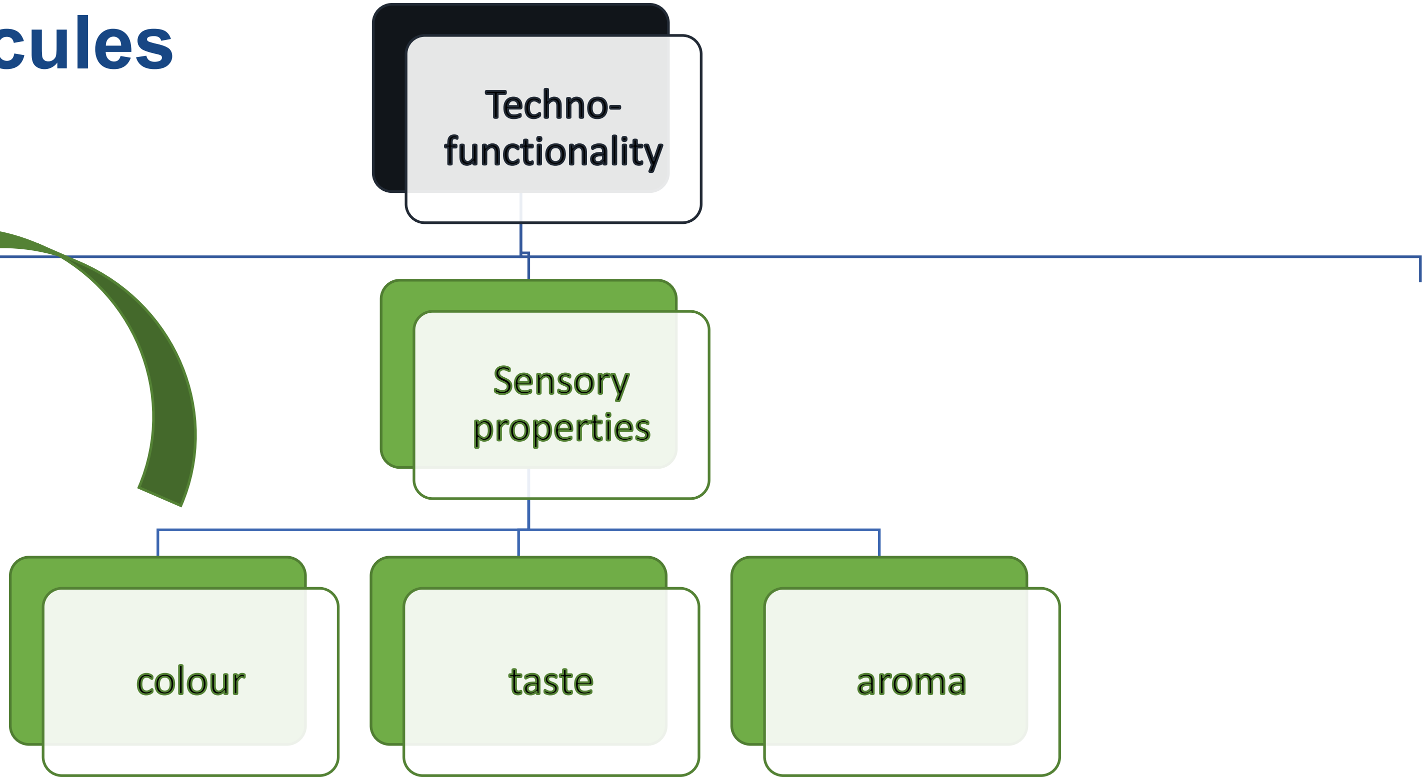
TF of food biomolecules



(synthetic, natural) molecules able to interact with and absorb visbile light

- **synthethic**
- **E-number (natural/modified)**
- **colouring foodstuff**

Concentrated natural plant/algal extracts containing natural pigments

Potential presence in food waste and side-streams

Colour
…

e.g.
Sweeteness
Salting
Bitterness
Sourness
Umani

Odorous compounds

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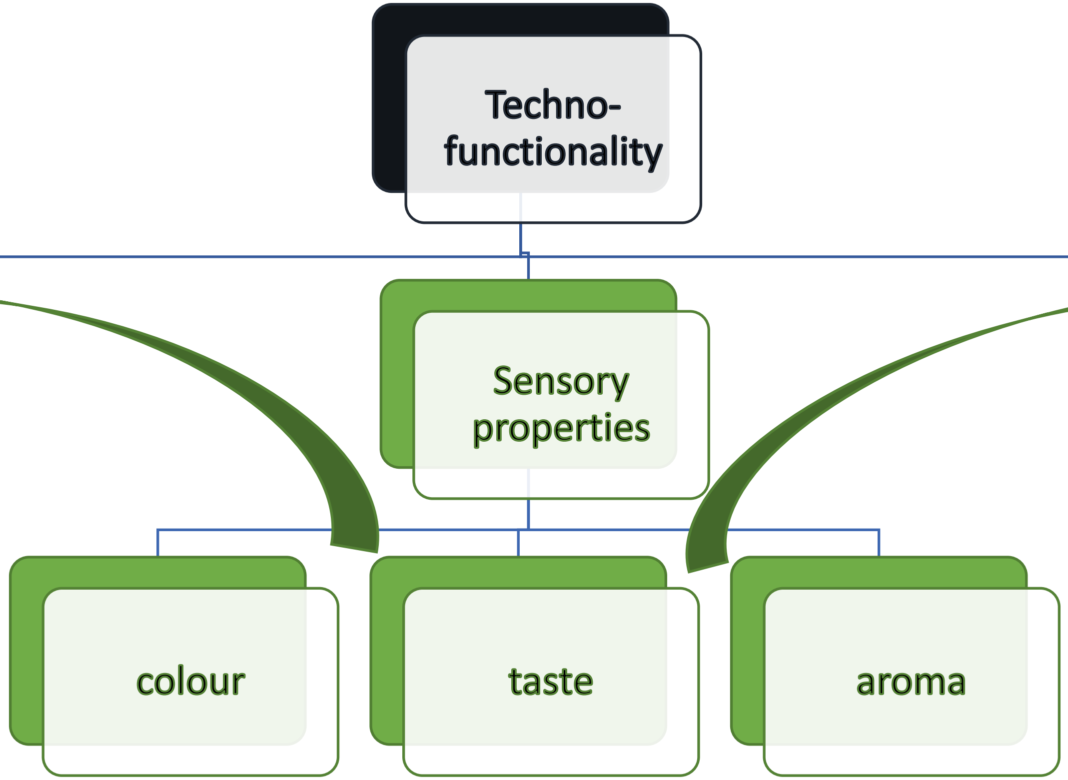

Salts, sugars, acids
- naturally present in foods

Potential presence in food waste and side-streams

Colour
…

e.g.
Sweeteness
Salting
Bitterness
Sourness
Umani

Odorous compounds

Bitter phenolic compounds, bitter acids, peptides
- naturally present

Potential presence in food waste and side-streams

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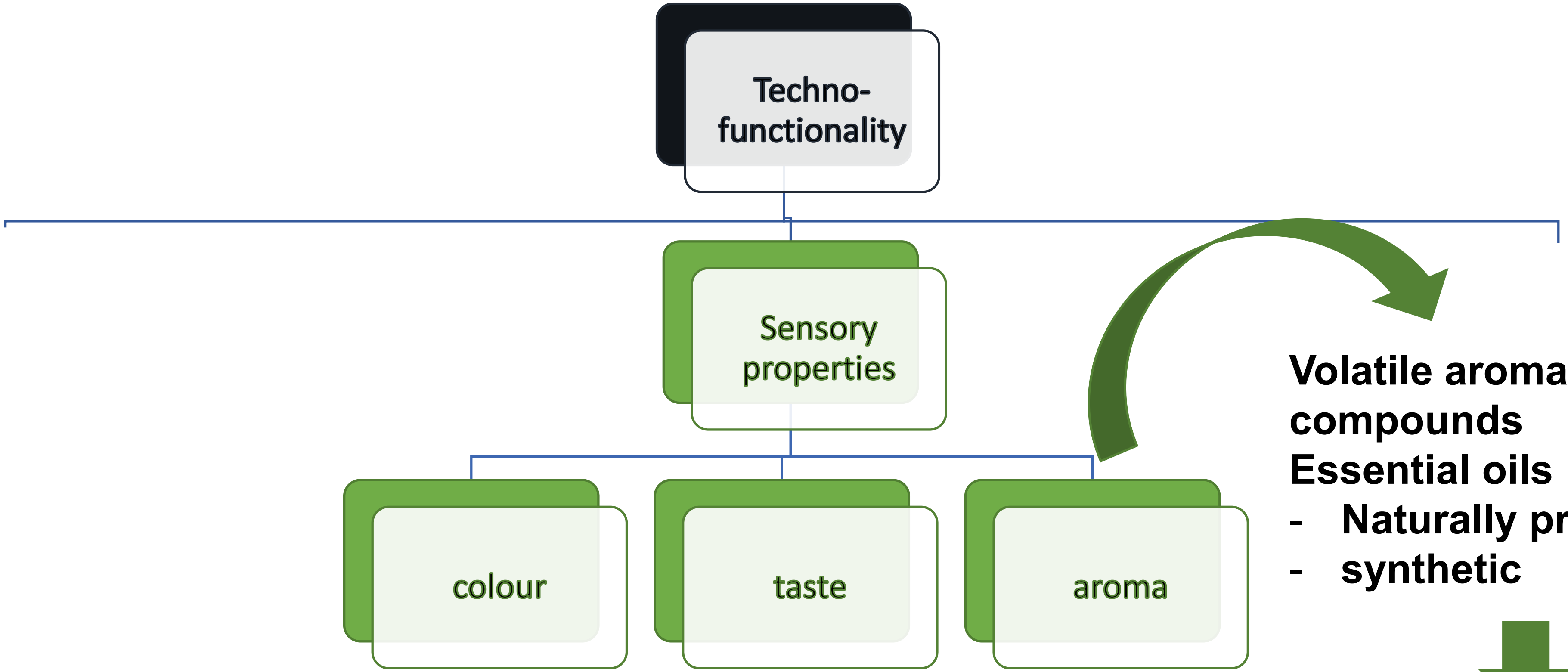

Colour
…

e.g.
Sweeteness
Salting
Bitterness
Sourness
Umani

Odorous compounds

Volatile aroma/odorous compounds
Essential oils
- **Naturally present**
- **synthetic**

Potential presence in food waste and side-streams

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Techno-functionality

Antioxidants and anti-microbials:

- Natural (e.g. plant extracts, terpens, glucosinolates derivatives, alkaloids, essential oils, pure compounds)
- Peptides
- Enzymes
- *Synthetic (e-number, use in foods regulated by law)*

Table 1. *Sources of Some Natural Antioxidants*[22,25]

Compounds	Natural Source
Carotenoids	Dark leafy vegetables, carrots, sweet potatoes, yams, tomatoes, apricots, citrus fruits, kale, papaya
Catechins	Green tea, berries, certain oilseeds
Flavonoids (polyphenols)	oilseeds, lettuce, berries, eggplants, peppers, citrus fruits, cruciferous vegetables, onions, black tea
Lycopene	Tomatoes, papaya, watermelon, guava,
Phenolic acids	Oilseeds and certain oils, cereals, grains
Vitamin C	Fruits and vegetables, berries, citrus fruits, green peppers, potatoes.
VitaminE(tocopherols)	Oilseed, palm oil, nuts, eggs, dairy products, whole grains, vegetables, cereals, margarine, etc.
Extracts	Extract from green tea, rosemary, sage, clove, oregano, thyme, oat, rice bran

stability

antimicrobial

antioxidant

Potential presence in food waste and side-streams

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Could be food waste ingredients and biomolecules valorized for their techno-functionality?

Could these raw materials, food waste and side-streams processing products become food ingredients (or additives?)

Issues and challenges

1. LEVEL OF PROCESSING

- **basic/minimal:** sanitisation, stabilisation (es. such)

e.g. powders, extracts…

High level of compositional complexity

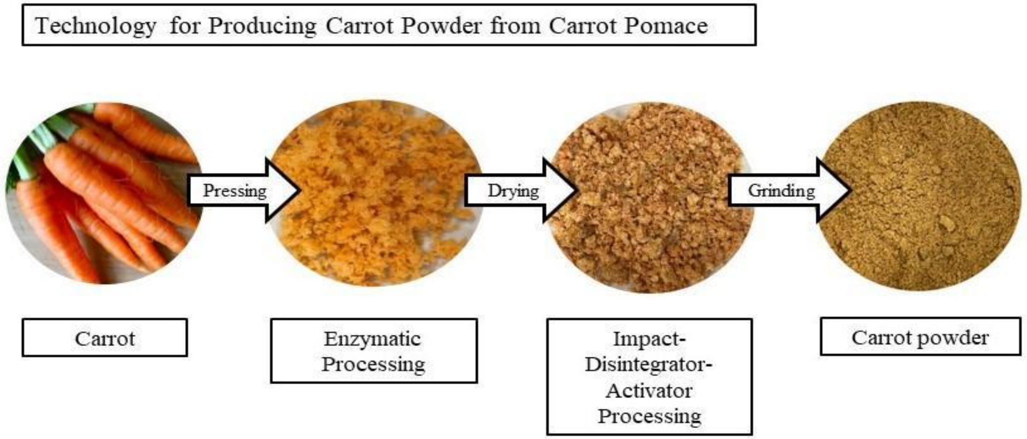
Use: bulking agents, colouring, flavouring …

- **advanced/biorefinery approaches** (extraction, isolation, purification)

- different levels

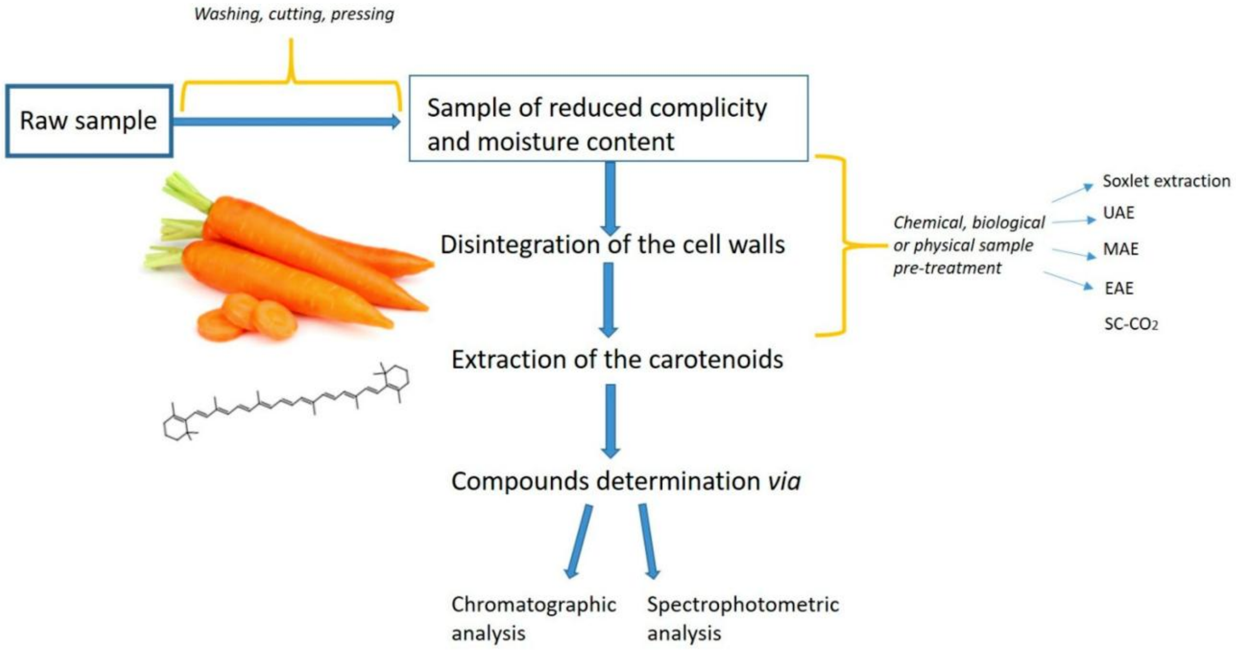
From simple solid-liquid separation (see above) to pure compounds/extracts (obtained by complex sequence of process stages) with specific techno- functionality

Issues and challenges



Baskovtceva et al., 2023
Carrot pomace
Use of Enzymes to enhance content of b-carotene in carrot powder

High health potential powder
Medium-impact processing



Mi¸ekus et al, 2019
Green Chemistry Extractions of Carotenoids from Daucus carota L.

Pure compound
High-impact (sustainable) processing

Food waste and side-streams: Technological functionality of biomolecules obtained from food waste (Pittia, 2018)

Compound	Origin/source of waste and by-products	Solubility	Technological/quality functionality
Pectins	Fruit and vegetable peels, pomaces	Water	Gelling and structuring Surface activity
Proteins	Meat (animal), Fish Milk (whey), Eggs Vegetables (legumes) (micro-)algae, seaweeds , Seeds	Water, Amphyphylic behaviour	Emulsifying and foaming activity, Gelling and structuring Binding (aroma, lipids) Antioxidant properties
Peptides and aminoacids	Meat (animal), Fish, Milk Vegetables, Seeds	Water Amphyphylic behaviour	Solubility, Emulsifying and foaming activity Bioactivity, Health properties
Oligosaccharides	Fruit and vegetables	Water	Solubility Healthy properties
Polysaccharides	Fruit and vegetables	Water	Water holding and binding properties Gelling and structuring
Hydrocolloids and gums	Vegetables, seeds	Water	Gelling and structuring Water holding capacity
Oils and fats	Meat, Fish, Seeds	Oil	Structure forming, Binding (aroma, proteins) Sensory properties
Phenolic compounds	Plant and fruit peels, pomace, and extracts	Water-to-oil depending on chemical structure and molecular weight	Antioxidant , Health properties Surface activity Sensory properties (colour and taste)
Phytochemicals	Plant extracts	Water-to-oil depending on chemical structure and molecular weight (Some) amphiphilic behavior	Solubility, Surface activity , Emulsifying properties Healthy properties
Pigments	Plant and fruit extracts, Algae and seaweeds residues, Meat (myoglobin)	Water-to-oil depending on the compound	Colour and sensory properties
Flavour compounds and essential oils	Plant and fruit extracts	Water-to-oil depending on the compound	Aroma and sensory properties

Issues and challenges

2. SAFETY AND REGULATIONS

a. **waste and side-streams may**:

- have high level of microbial and chemical contamination
- highly prone to degrade (enzymes, chemical reactions, microbial growth)

→ **stabilisation, sanitisation**

b. Valorisation of biomolecules not used for food purposes

- approval required to become food grade according to the (EU) «novel foods» regulations

Issues and challenges

3. COSTS and ECONOMIC benefits

- Each process/step has specific costs (end environmental impact)
- Evaluate the availability of technologies + need of process optimisation
- Need to evaluate costs/benefits in relation to the added-value and technological potential of the final product

4. SKILLS and Human Capital COMPETENCES

- Food waste and side-streams management and processing skills
- Sustainability and green skills

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Thank you

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Waste valorisation in food product design

Session : Circular economy, industrial sustainability and social impact

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Agenda

1. The limits of growth.
2. Principles of the circular economy.
3. Industrial sustainability.
4. Social impact of the circular economy.

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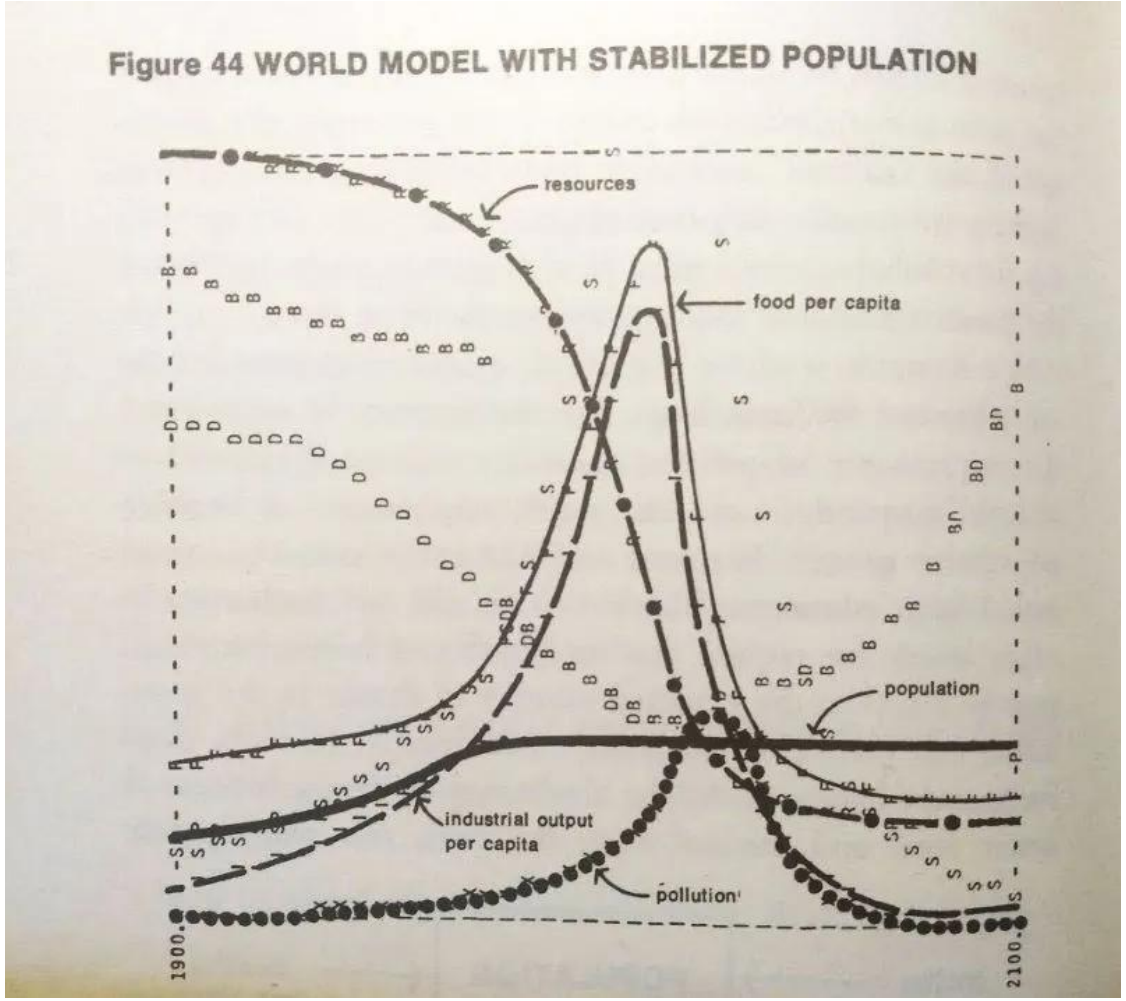
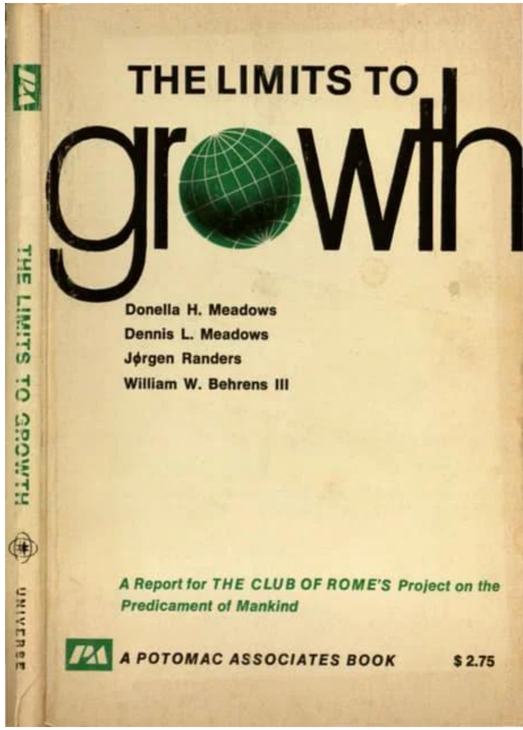
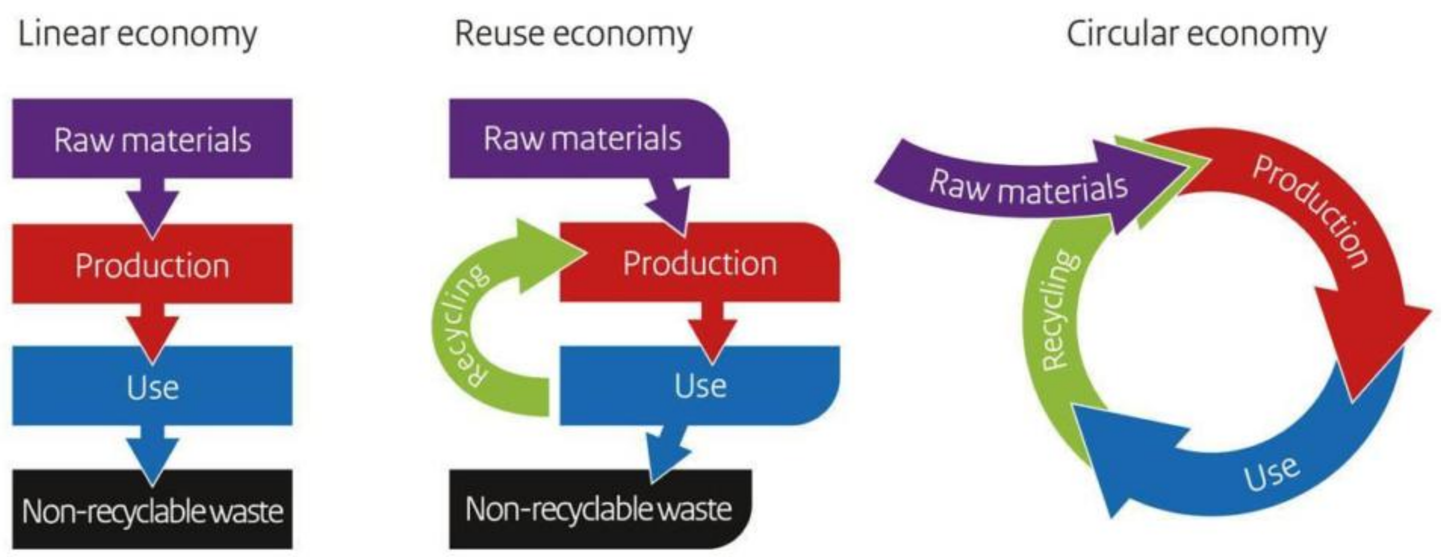
1. The Limits of growth. Club de Roma 1972.

- World has interconnected systems
- If growth trends continue unchanged there is a large possibility of an overshoot of the carrying capacity of the Earth in the next 100 years





1. From a linear to a circular economy



https://umaine.edu/sustainability/2021/04/25/food-waste/

2. The Circular Economy model

2. Principles of circularity

Reduce:

- Minimize the use of raw materials and energy in the production process.

Reuse:

- Extend the lifespan of products through repair, refurbishment, and re-purposing.

Recycle:

- Recover valuable materials from end-of-life products and use them in new production cycles.

Recover:

- Extract energy from waste materials through incineration or other processes.

Design for Circularity:

- Develop products and systems that are designed to be easily repaired, reused, and recycled.

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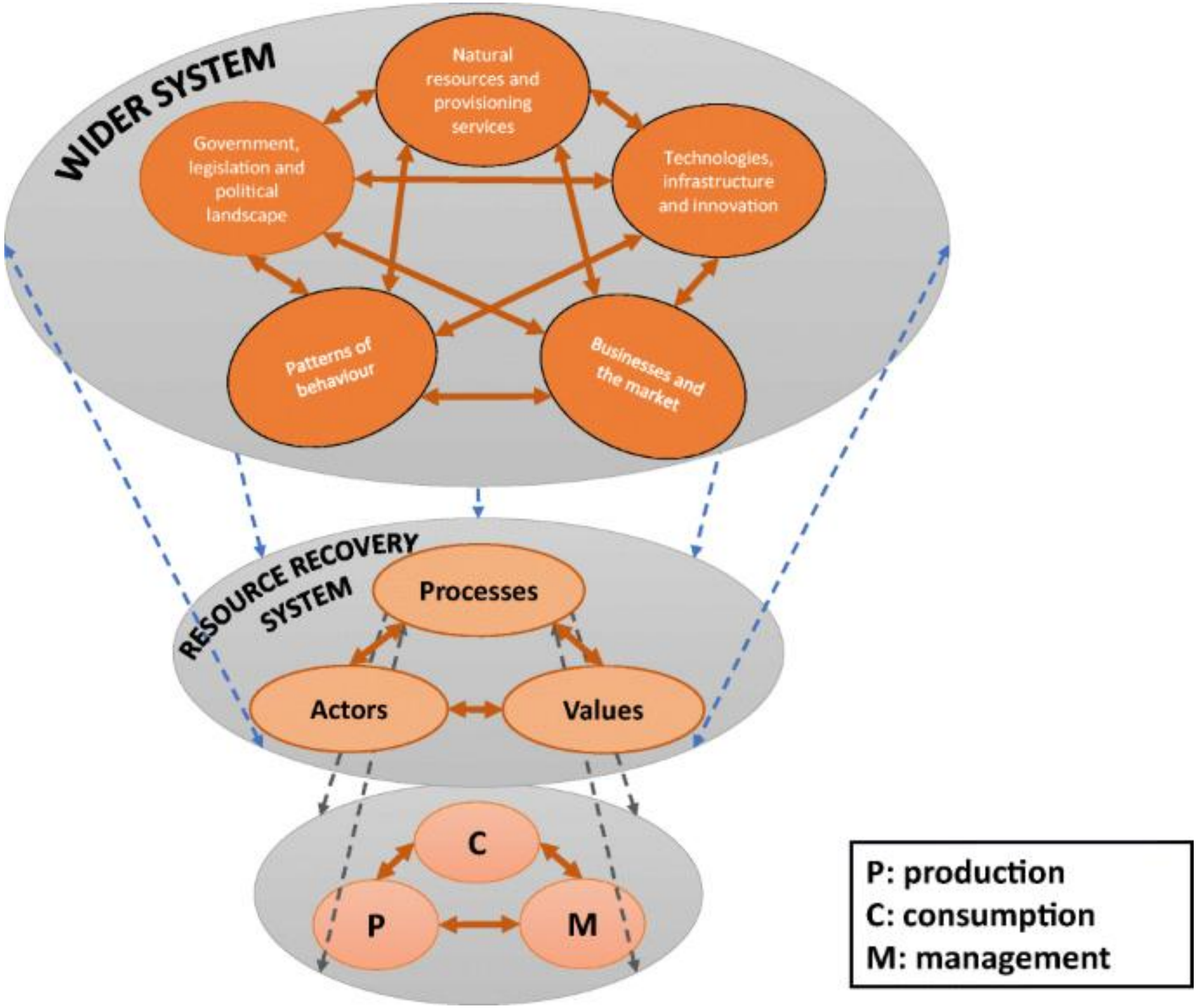
2. Circularity and Systems Thinking



https://link.springer.com/article/10.1007/s11356-020-11725-9

3. Circularity and industrial sustainability

Resource Efficiency: Circular economy practices encourage industries to use resources more efficiently, reducing the demand for raw materials and energy.

Waste Reduction: By designing products for durability, reparability, and recyclability, industries can significantly reduce waste generation.

Innovation: Circular economy initiatives can drive innovation in product design, manufacturing processes, and business models, fostering new industries and creating economic opportunities.

Climate Change Mitigation: Reducing waste and resource consumption through circular practices can lead to a reduction in greenhouse gas emissions, contributing to climate change mitigation efforts.

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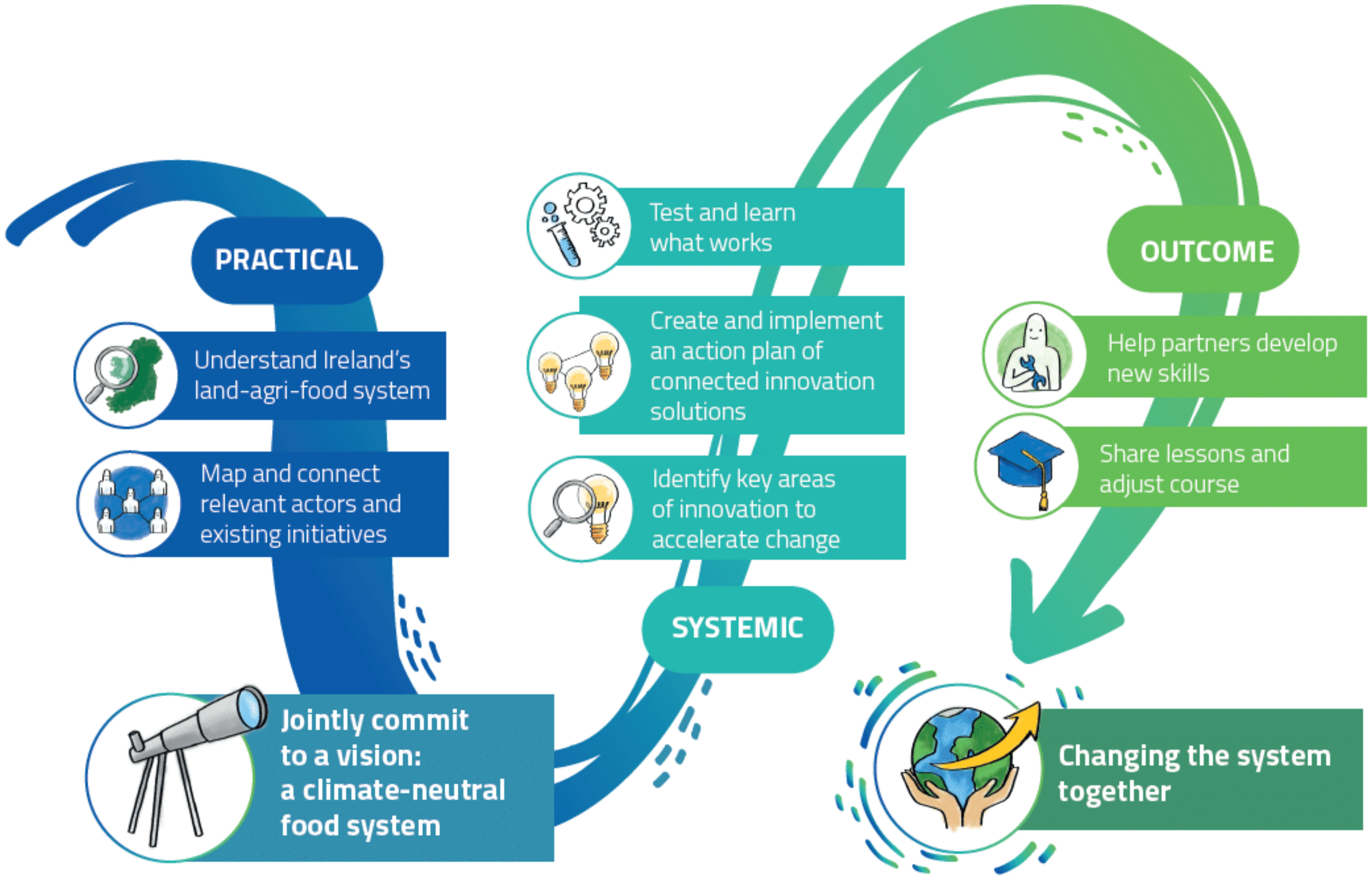
4. Changing the system. Climate KIC Deep Demonstration Transforming Ireland Agrifood system



4. Seven Social Impact Areas of the Deep Demonstration for Ireland

- 2050 focus
  - Vision 2050: re-imagine Ireland's land and agri-food system
  - Grow the sector through innovation and investment in new value chains
  - Implement circular bio-economy models at regional or multiple value chains level
- 2030 focus
  - Diversify incomes through carbon farming and nature credit frameworks
  - Produce and certify climate-neutral beef
  - Accelerate emission reduction and sustainability in dairy farms
  - Grow and diversify the tillage sector

https://www.climate-kic.org/wp-content/uploads/2023/03/EIT-Climate-KIC-Ireland-Land-Agri-Food-Systems-Map.pdf

Additional target mitigation measures for agriculture and land use by 2030

- A reduction of at least 10% in biogenic **methane.**
- A reduction of 5% (below 2005 levels) in ammonia emissions, to improve **air quality**.
- A reduction of over 50% of nitrous oxide emissions associated with **chemical fertiliser.**
- A reduction in nutrient losses from agriculture to water, to improve **water quality by 50%.**
- At least 7.5% of utilisable agricultural area to be **farmed organically**.
- Achieving 30% of marine protected areas, to improve **seafood** sustainability.
- Double the sustainable production of **biomass from forests** to 2 million tonnes (by 2035)

Thank you

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