The CropBooster-P Roadmap

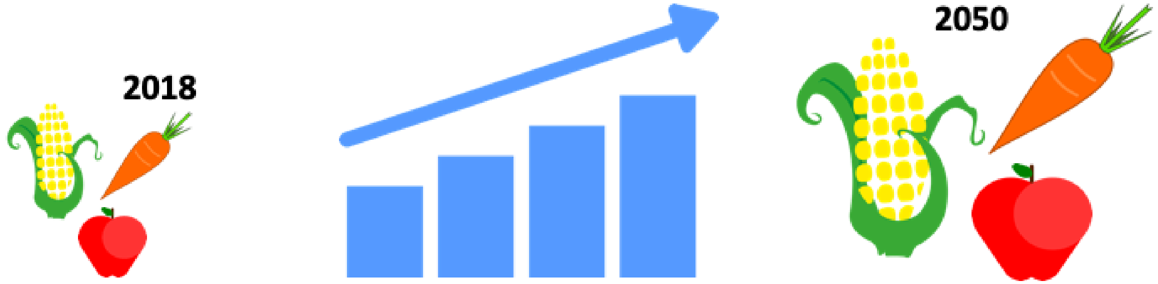
PAVING THE WAY TOWARDS FUTURE PROOFING OUR CROPS

Annual meeting – Wageningen
Dr. Alexandra Baekelandt
26th of April 2022

European Commission
Horizon 2020
European Union funding
for Research & Innovation

CropBooster-P - Future Proofing Crops

We need to match future research programs to the values, needs and expectations of society



Aims

- Develop a roadmap for future proofing our food system and the European bio-economy – **paves the way for future research and innovation.**
- Focusing on the potential for plant improvement to help enhance **yield**, enhance **nutritional quality**, and ensuring environmental **sustainability**.

Yield: Increasing the total amount of edible or usable material produced by the plant.

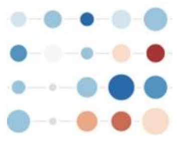
Nutritional quality: Increasing the amount of plant components which are beneficial to human health (or decreasing the amount of those which are harmful to human health).

Sustainability: Improving how plants use resources and cope with stresses like heat or drought.

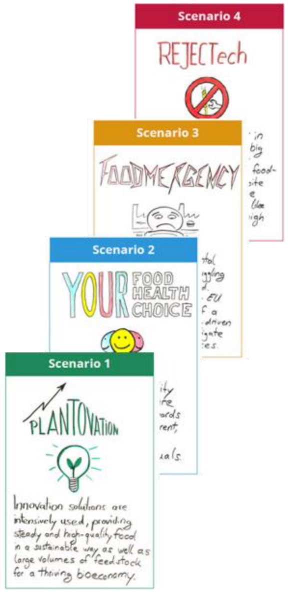
Overview of how the Roadmap is developped

Setting the option space for Yield, Nutrition and Sustainability

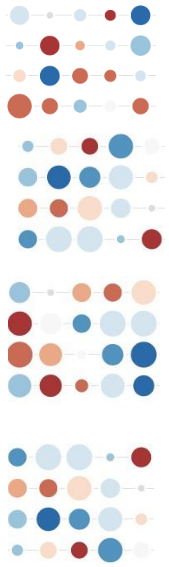
CropBooster "As is" 2019



Future worlds 2050



Alternative outcomes



WP 1

Multidimensional assessment of the option space

WP 2

Economic, Social and Environmental Impact

WP 3

Societal Needs and Expectations

WP 4

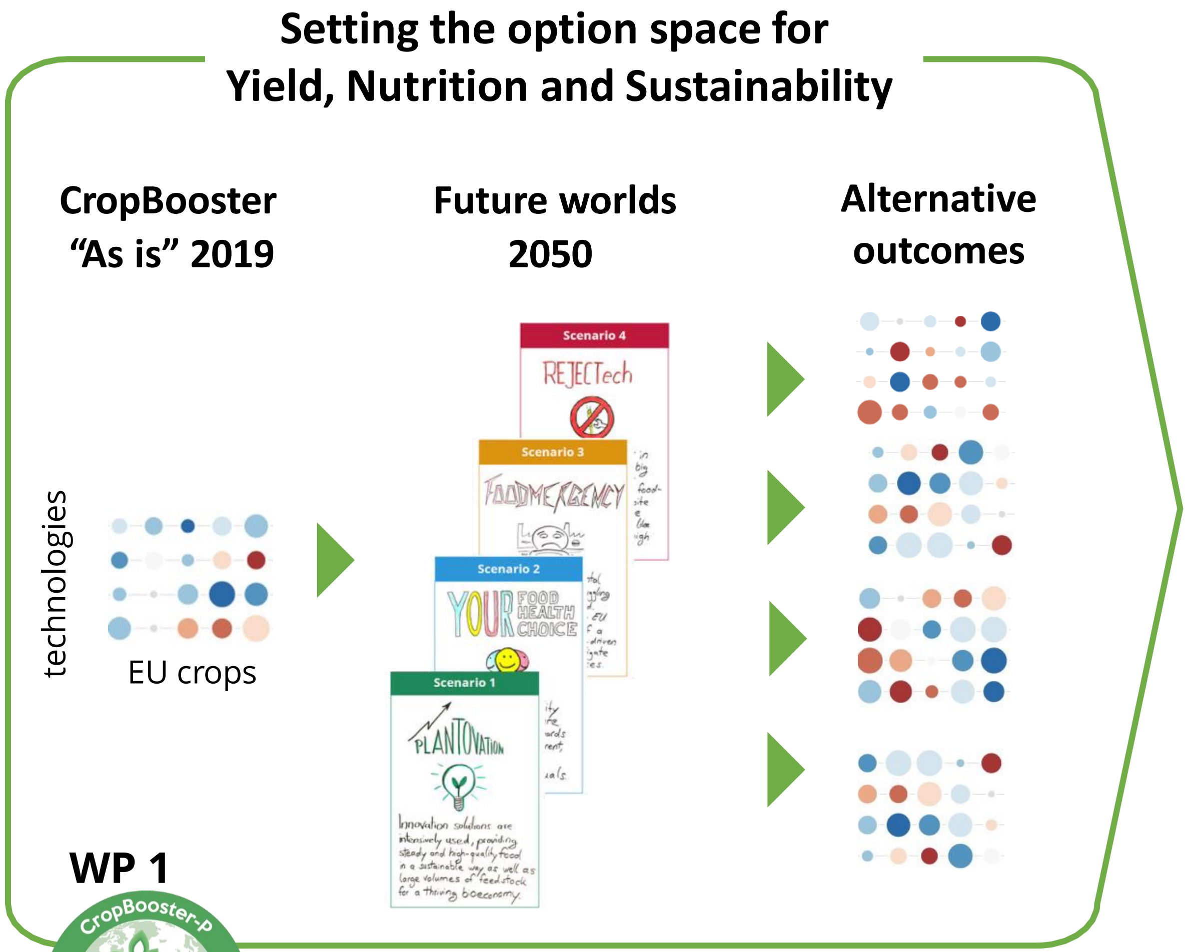
International Cooperation

Strategy Development

WP 5

- Roadmap to future proof the EU crops
- Improved societal awareness and engagement
- In depth anticipation of economic, social and environmental impacts

Overview of how the Roadmap is developped



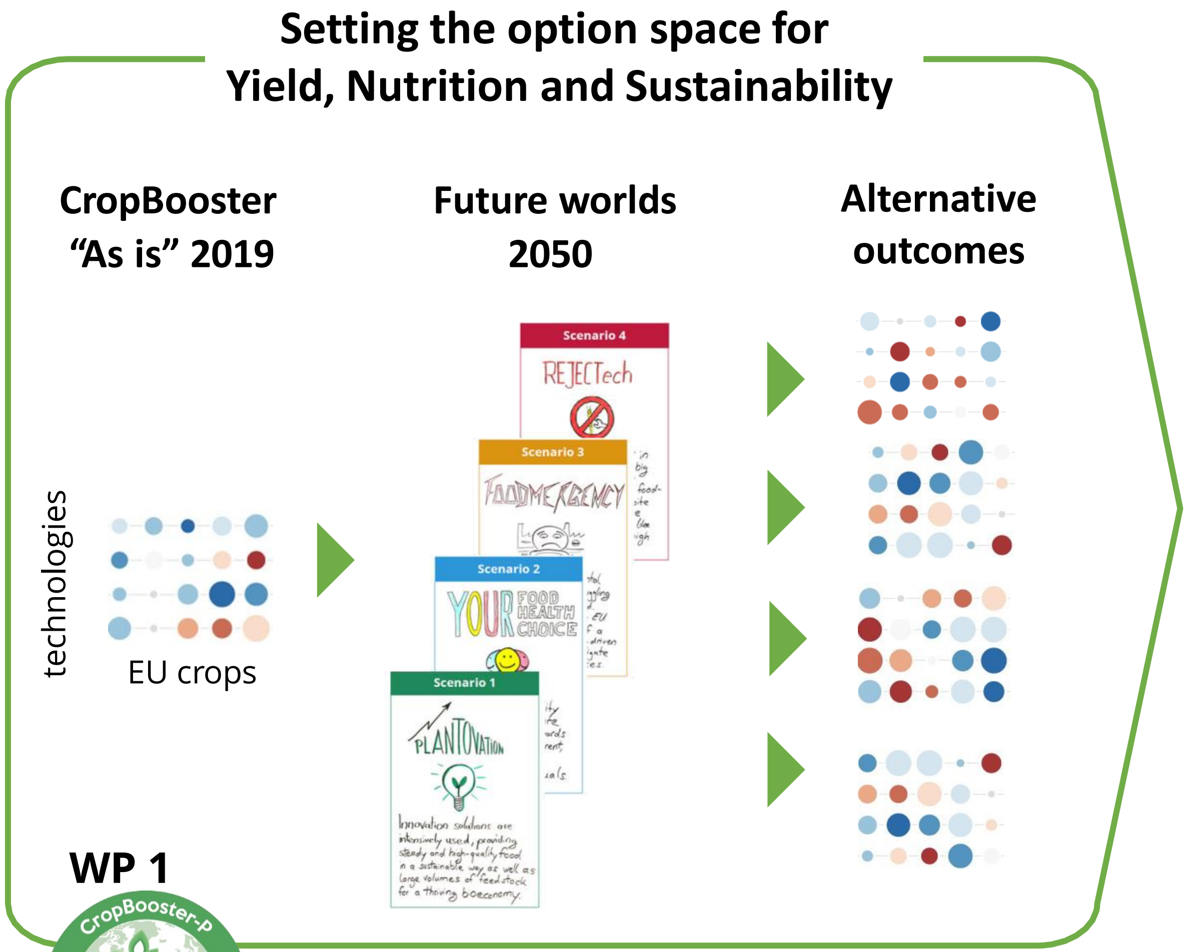
3 phases:

(1) Options for crop improvement

(2) Run your plan against a range of possibilities - Create Future worlds - Scenario building analyses

(3) What is the impact of the scenarios on the crop improvement options?

Overview of how the Roadmap is developped



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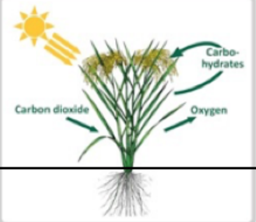
(3) **What is the impact of the scenarios on the crop improvement options?**

WP1: Options for crop improvement

What determines/affects YIELD POTENTIAL (genetic basis) – YIELD DETERMINANTS?
Which plant traits/functions are heritable/transferable and do we have to take into account in this project because they may determine plant YIELD POTENTIAL?
YIELD POTENTIAL <-> actual yield (YIELD POTENTIAL+ ENVIRONMENTAL CONSTRAINTS (e.g abiotic stresses - SUSTAINABILITY))

Define key options to improve ***Yield***, Nutritional Quality and Sustainability

1 *The Biochemistry* **and photochemistry of photosynthesis**



The Canopy

4 *The Leaf* **Plant growth, architecture and phenology**

3 *Sources and Sinks*

2 **Uptake and spatial management of resources (tightly linked with SUSTAINABILITY)**

WP1: Options for crop improvement

Yield	Plant growth, architecture and phenology 4	Shoot architecture and canopy profile	Phyllotaxy Self-shading Compactness Stem anatomy and composition Profile of photosynthetic resources Leaf angle (erectness) Leaf morphology/shape Organ length/width Other	Stress - Heat Stress - Cold Stress - High humidity Stress - Flood Stress - Drought Stress - Salinity Stress - Toxicity Stress - Nutrient overload Stress - Nutrient deficiency Stress - Soil toxins Stress - Soil composition Stress - pH Geographical factors
		Leaf anatomy	Cuticular thickness Wax/cutin ratio and content Stomatal properties (morphology, densities, distribution, location and resistance) Mesophyll thickness Mesophyll conductance Mesophyll resistance Mesophyll structure Vessel anatomy (density, structure) Organelle properties (density, positioning and movement) Other	
		Growth rate	Meristem activity Cell division Growth mechanics Cell expansion Cell wall composition Cell turgor Other	

TRAIT

CROP TYPE

SPECIES

GENETIC PATHWAY

GENES/ALLELES/MARKER

DESCRIBED ORTHOLOGS IN OTHER CROPS

OBSTACLE TO TRANSFERABILITY

IMPACT ON YIELD/SUSTAINABILITY/NUTRITIONAL QUALITY (YES/NO, HOW)

DOI

TITLE

AUTHOR

YEAR

UNIVERSITY

ABSTRACT (text – text searchable – processing via text mining tools)

TECHNICAL APPROACH (how was the relevance demonstrated e.g GMO)

CROPBOOSTER-P SURVEY

Partners Information- This section is for INTERNAL USE only, to make certain all partners (and consequently, fields of expertise) are represented in the data collection.

*Vereist

Name *

Jouw antwoord

Affiliation *

Jouw antwoord

VOLGENDE

Verzend nooit wachtwoorden via Google Formulieren.

→ ***GOAL: To <u>collect the data</u> covering important keystone/state-of-the-art publications and/or breakthroughs in the field of Y, S and NQ***

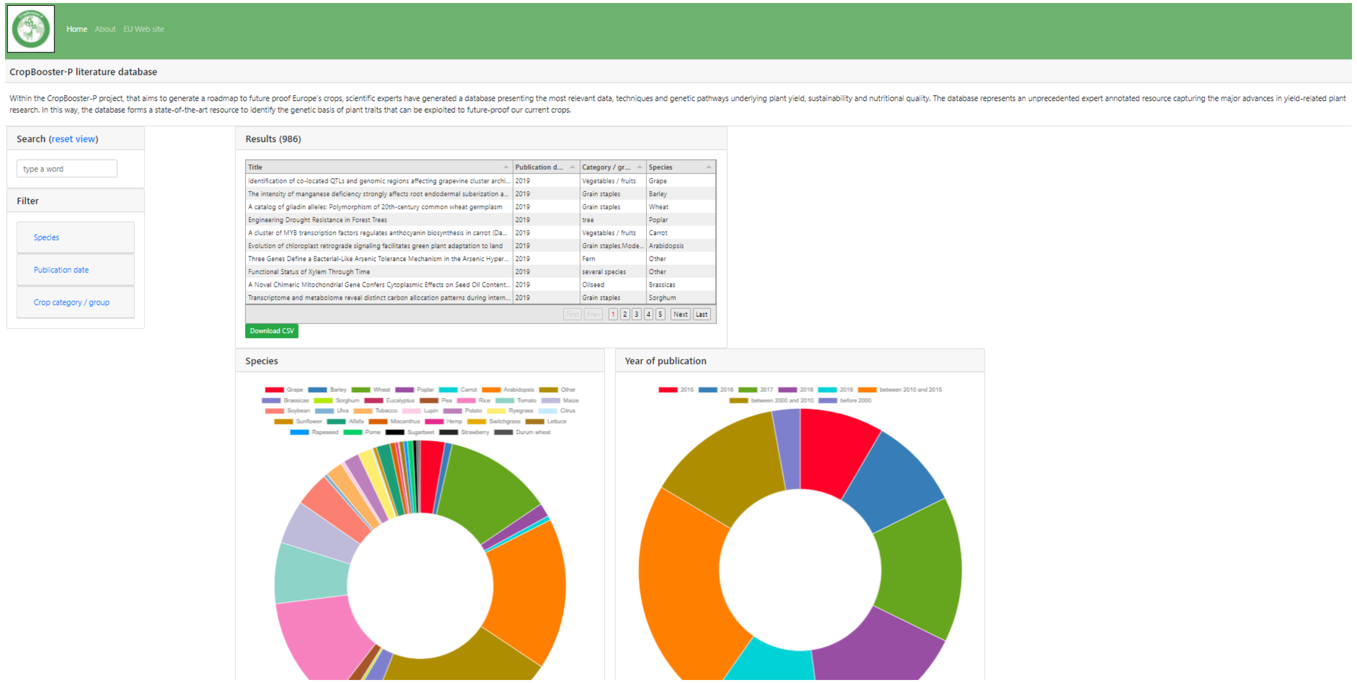
CropBooster-P

European Commission

Horizon 2020
European Union funding
for Research & Innovation

WP1: CropBooster-P Database

https://cropbooster-p.wur.nl/



→ ***FOLLOW-UP: The data collection document is <u>transformed to an Open Access Database</u>.***

- This database is a **literature repository containing scientific state-of-the-art keystone publications** on possibilities to improve crop Y, S and NQ.
- Expert resource, useful for the European plant science community at large.

Baekelandt *et al.*, 2021

WP1: The 15 Crop-Boosting options

Yield

- Improving photosynthesis
- Increasing the size of harvestable parts
- Improving the use and movement of nutrients within the plant
- Altering the growing season of plants
- Improving the digestibility of biomass

Nutritional Quality

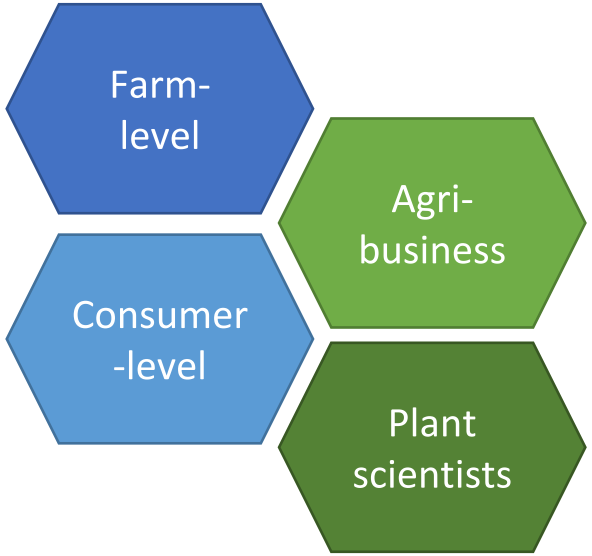
- Increasing vitamin and mineral content
- Increasing protein content and quality
- Decreasing negative and toxic compounds
- Increasing antioxidant content
- Producing healthy omega-3 fatty acids in oilseeds

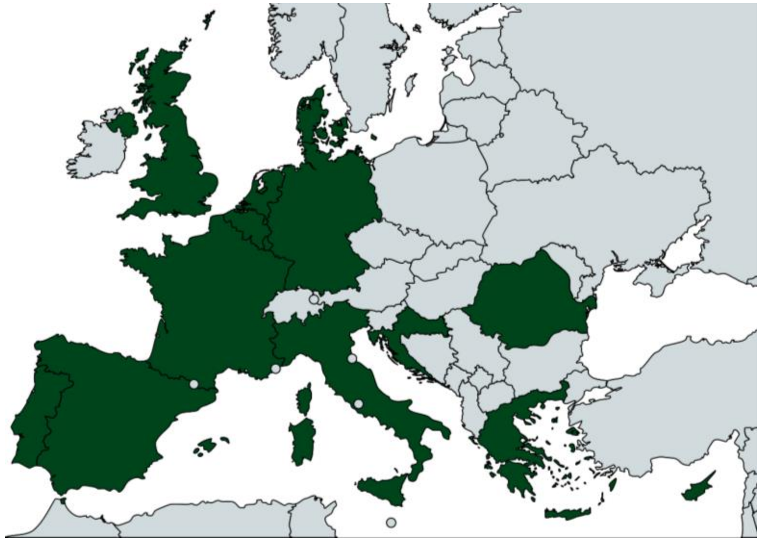
Sustainability

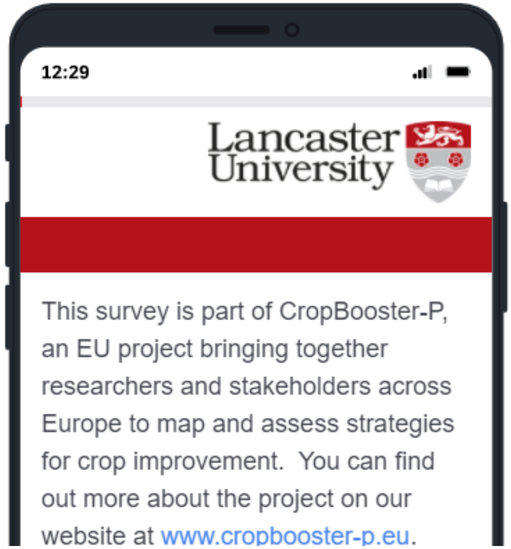
- Improving Nitrogen uptake and use
- Improving plant water use
- Improving phosphorous uptake and use
- Improving salt stress tolerance
- Improving heat stress tolerance

Scharff *et al.*, 2021
Gojon *et al.*, 2022
Burgess *et al.*, in prep

WP2: Assessing socio-economic and environmental impacts



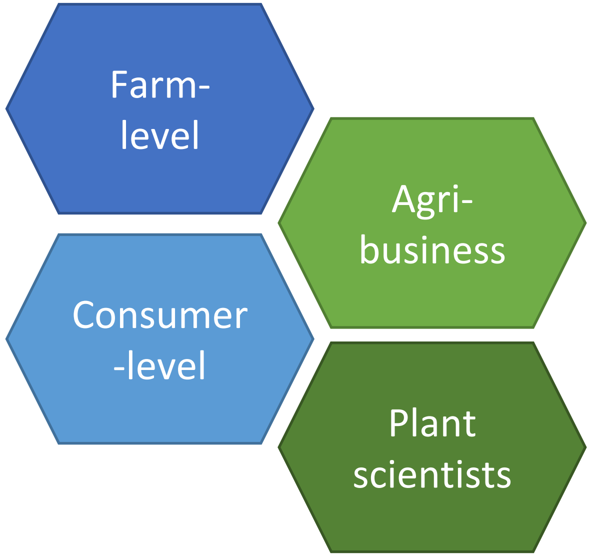




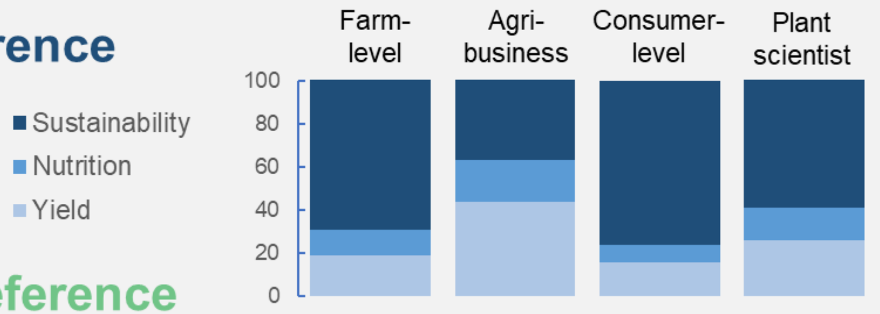
1. Which goals – Yield, Nutrition, Sustainability – do people feel are most important?
2. Which options are most important?
3. Do different stakeholder groups have different opinions?

WP2: Survey and workshop highlights

*"...All must be sustainable in longer term. These are **not mutually exclusive** and we should be **aiming to have them all**"*



Goal Preference



Option Preference

		Farm-level	Agri-business	Consumer-level	Plant scientist
Sustainability	Improving plant water use	92	96	97	97
	Improving heat stress tolerance	90	73	94	74
	Improving Nitrogen uptake and use	85	85	92	85
	Improving Phosphorus uptake and use	79	85	80	85
	Improving salt stress tolerance	58	54	68	54
Yield	Improving photosynthesis	79	69	62	70
	Improving digestibility of biomass	50	38	46	39
	Use and movement of nutrients within the plant	53	65	57	66
	Altering growing season of plants	55	65	54	66
	Increasing the size of harvestable parts	41	38	42	39
Nutrition	Improving protein content and quality	64	73	69	74
	Increasing vitamin and mineral content	55	65	72	66
	Increasing antioxidant content	58	50	57	51
	Decreasing negative and toxic compounds	51	54	69	54
	Producing healthy omega-3 fatty acids in oilseeds	53	50	60	51

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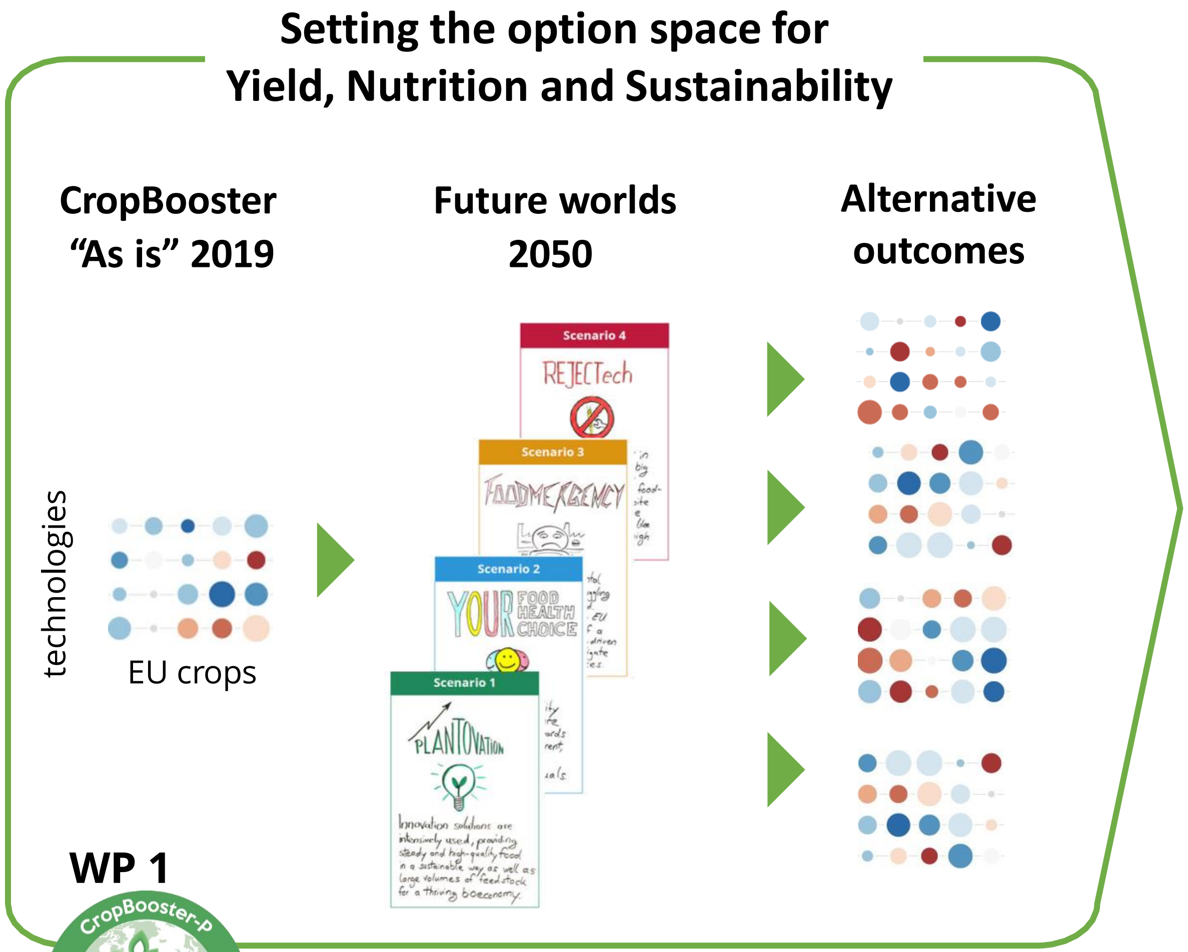
Overview of how the Roadmap is developped



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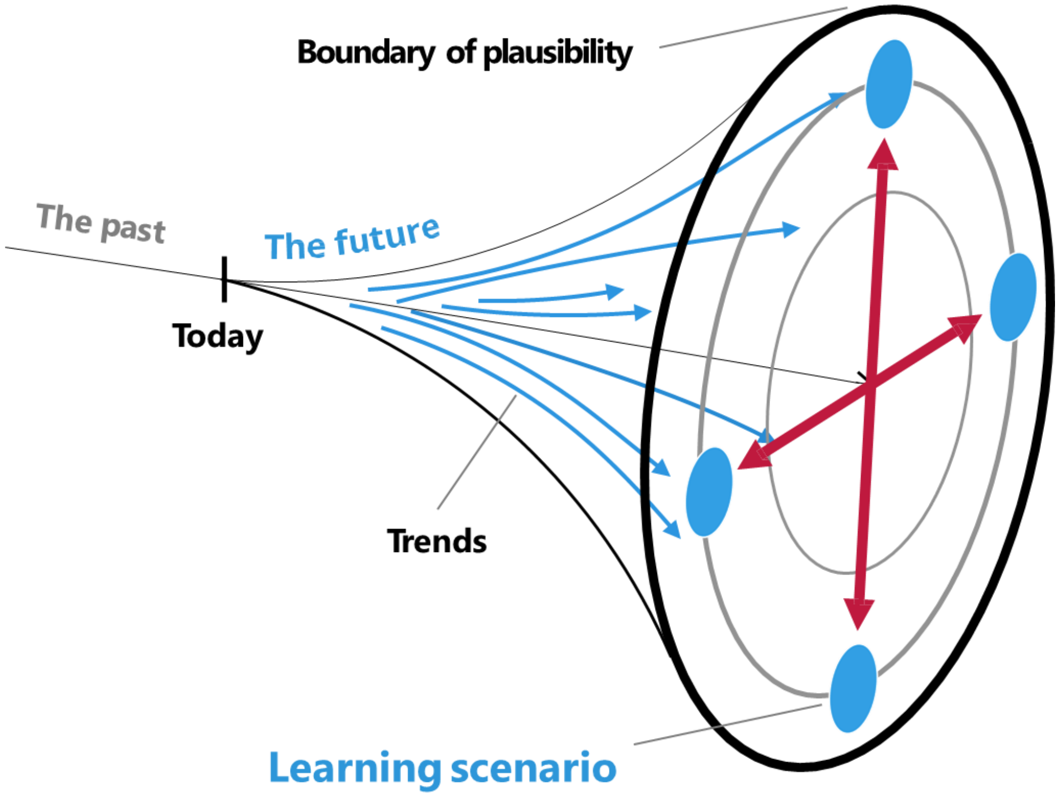
WP1: Scenario building analyses



Learning scenarios serve as a general framework for outlining future worlds

External consultants: Sommerrust

Scenarios are not predictions: one can't predict complex (social) systems in the long-term

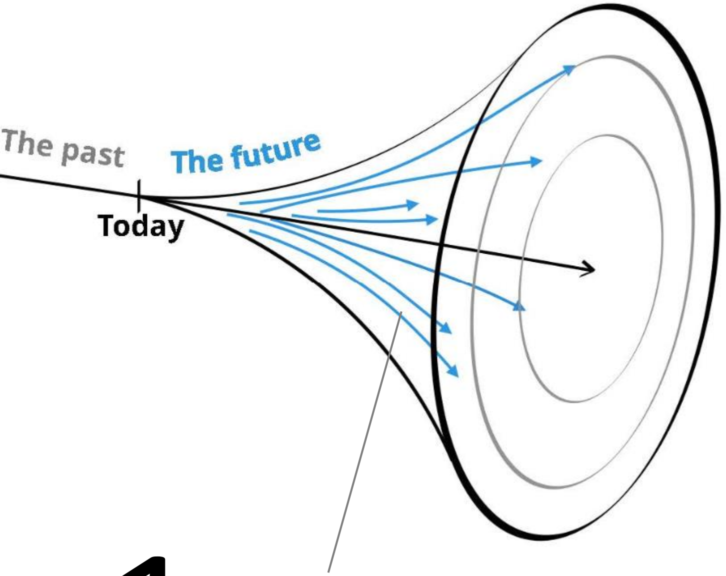
Scenarios are never implausible e.g. based on inconsistent combination of outcomes or on extremely unlikely events

Scenarios differ from each other to cover a **wide range of possibilities**; key uncertainties play out differently

By design, each of these four scenarios is **plausible**

Cornelissen *et al.*, 2021

WP1: Scenario building analyses - Trends



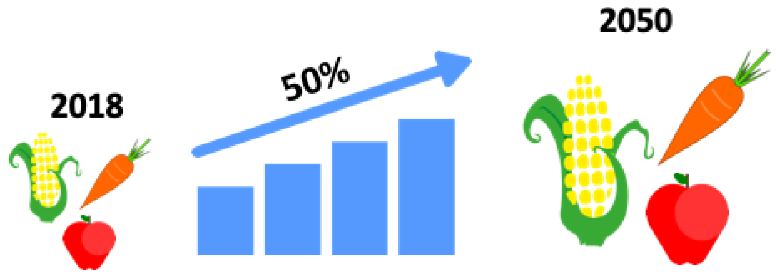
1 **Trends**
continue to "push"
in a given direction

45 different technological, economic and societal Trends

Demographic Trends
(e.g. aging population)

Farming Trends
(e.g. pressures on farm)

Consumer Trends
(e.g. environmental concerns, animal welfare)

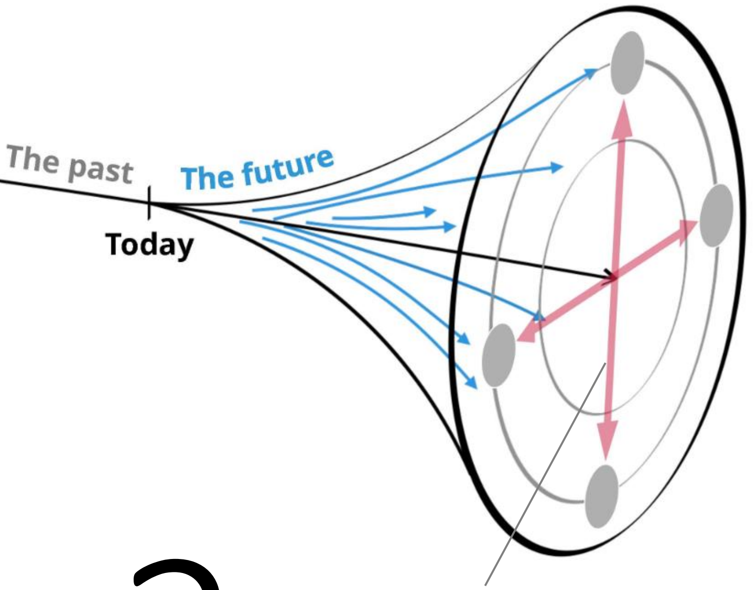


Politics , Economy & Society Trends
(e.g. globalization, decreased trust)

Sustainability Trends
(e.g. climate change, resource scarcity)

Cornelissen *et al.*, 2021

WP1: Scenario building analyses – Key uncertainties



2 **Key Uncertainties** play out differently for each scenario

Uncertainties

Needs for adaptation	Limited impact	● **Impact of environmental changes[1]**	Heavy negative impact
	Healthy, small population	**Development of demography[2]**	Large, unhealthy population
	Stable, prosperous economy	**Development of the economy[3]**	Poor, volatile economy
	Collaborative, open markets	**Development of the political environment**	Isolationism
Priorities in the value chain	Not important	**Importance of sustainability[4]**	Important and relevant
	Focus on food	● **Role of the bioeconomy: food vs non-food**	Strong demand for non-food
Role of science	Breakthroughs and adoption	**Development of advanced biotech**	Ban of wide range of biotech
	Breakthroughs and adoption	**Development of nonbiological tech[5]**	Failures and abandonment
	Very high	● **Influence and reputation of scientists**	Very low

1 e.g., climate change, resources scarcity, development of pests, loss in biodiversity,...
2 e.g., size of population, age, chronic diseases,...
3 e.g., prices, income, equality,...
4 e.g., environmental concerns, animal welfare, organic farming,...
5 e.g., robots, AI, VR/AR, blockchain,...

Cornelissen *et al.*, 2021

WP1: Scenario building analyses– 4 Learning scenarios

When biotech innovation thrives

Scenario 1: Bio-Innovation

Innovative solutions are intensively used, providing steady and high-quality food in a sustainable way as well as large volumes of feedstock for a thriving bio-economy.

When consumers become king

Scenario 2: My Choice

Health and sustainability concerns drive agriculture and food businesses towards being diverse and transparant, meeting the needs and preferences of individuals.

When food runs out

Scenario 3: Food Emergency

Due to severe environmental degradation, the EU is struggling to fulfill basic food demand. In response to the crises, the EU has seen the introduction of a large-scale and technology-driven agricultural system to mitigate the most direct consequences.

When science loses society

Scenario 4: REJECTech

Consumers have little trust in politicians, scientists and big industry. Society is highly polarized and rejects new food-related technologies, despite the dissatisfaction with the current state of affairs like limited food choice and high prices.

Cornelissen *et al.*, 2021
Baekelandt *et al.*, 2022

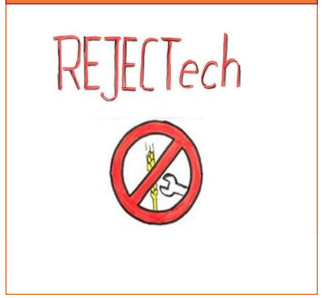
Four Scenarios

Scenario 1: Bio-Innovation

Scenario 2: My Choice

Scenario 3: Food Emergency

Scenario 4: REJECTech



- The four possible future learning scenarios depict **future socio-economic developments**.

- The scenarios have a specific impact on **prioritizing crop improvement options** and consequently plant research focus areas.

- They delineate the future space considering
  - (1) what ***crop traits*** will need to be engineered to meet the needs of future society,
  - (2) which ***type of crops and plant species*** should be in focus in the European agricultural context, and
  - (3) what ***technical possibilities*** will be available to future-proof crops and which ones should be considered and implemented.

‘Plantovation’

Options would be unlimited and solutions are widely used for a thriving bio-economy for food, feed and fodder. Also the implementation of more complex traits can be made possible.

There are **no restrictions on research and technology**. The full range of conventional and biotechnological options can be exploited to meet the future needs.

Key options and technologies can be **implemented relatively quickly** and will allow targeted gene **transfer in all species** in a very short time frame. The shorter turnover period will enable researchers to quickly determine **what works and what does not**.

‘Plantovation’

Equal focus on **Yield**, **Sustainability** and **Nutritional quality** can be envisaged to improve crop productivity.

Resulting in **broad consumer choices** *(e.g. sustainable agriculture, tailored diet options, long shelf lives and big varieties of products)*

Note: Many of the major modifications at different levels are only possible using NPBTs.

‘Plantovation’

S improvement is equally in focus

e.g. stress resistance and nutrient partitioning for earlier harvest and less environmental pressure, modify stomatal ABA sensitivity to improve drought tolerance, ‘C4 wheat’, ‘nodulating wheat’

Y improvement by both exploiting natural variation and introducing new genes and pathways

NQ improvement is equally in focus

e.g. express long chain poly-unsaturated fatty acids to improve nutritional quality

'Your Food. Your Health. Your Choice.'

YOUR FOOD HEALTH CHOICE

A strong focus on personalized approaches, resulting in need for a greater variety of crops, with less dominance of the current major crops to meet a wide range of consumers specifically.

There are **no (or few) restrictions on research and technology**. The full range of conventional and biotechnological options can be exploited to meet the future needs.

Note: Despite the major benefits of NPBT crops, thus far it is proven extremely difficult for these crops to be adopted by agriculture (farmers and consumers), as for instance seen by the consumer rejection of Golden rice, enriched in Vitamin A.

Informed and mainly driven by consumer choices. **The high degree of personalization would slow down the speed of turnover** (e.g. safety regulation and rigorous testing before innovations would be made available).

‘Your Food. Your Health. Your Choice.’

S improvement will be in main focus

e.g. produce alternative crops with increased resilience to environmental stress and resource use efficiency to minimize environmental impact (e.g. locally and specifically manipulating ABA signalling to increase plant drought tolerance)

NQ improvement is also in main focus

e.g. increased demand for alternative nutrient sources, crops with improved micronutrient content and specialized metabolites with nutritive roles, including antioxidants, polyphenols, crops producing specific compounds or drugs

Y improvement to improve specific traits required by consumers or to address possible negative trade-offs observed between Y and NQ

e.g. but also increase shelf life and longevity demands and seed filling. increased Y to higher CO_2 in C3 plants tend to lead to a decrease in protein and a mineral content in seeds

Likely a niche production for most species/varieties

‘FoodMergency’

The priority is proposed to be set on calorie production. Very likely, only little effort will be put towards non-food biomass production.

Technologies are available and exploitable. Engineering crops can be done either by breeding, QTL introgression or by using NPBTs.

A rapid adoption and application of new approaches will be needed to maximally avoid food shortages.

‘FoodMergency’

Y improvement will be the main driver for innovation to maximally assure food security
e.g. organ growth and development, longevity, nutrient remobilization and partitioning, increased seed filling

S improvement will also be a main driver to improve yield stability
e.g. due to more extreme weather events caused by global climate change, the emergence of a global pandemic, the outbreak of war on the European continent

Due to the pressure on food security, there is little to no emphasis NQ improvement other than providing the basic nutrient requirements that the crops are able to produce. Putatively resulting in decreases in terms of tailored diet options and food.

‘REJECTech’

The priority is proposed to be set on calorie production. Very likely, only little effort will be put towards non-food biomass production.

A large number of biotechnological methods would not be accepted by society (e.g. general mistrust in science, policymakers and the agri-food systems). Many of the improvements may therefore even be impossible (e.g. dissecting complex signalling pathways (e.g. synthetic biology)). **Conventional breeding programs and traditional agricultural practices** would come again to the foreground.

Note: Changes will not be able to control as precisely as modern precision editing techniques, possibly leading to a lot more variation, unpredictability and inconsistency of results, putatively strengthening further mistrust of consumers in science.

Technological innovations and crop improvement would require **much larger timeframes**, so that they in practice will be very **limited**.

‘REJECTech’

REJECTech

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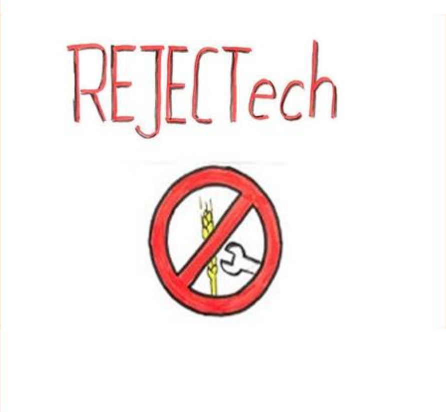
What about ENVIRONMENTAL sustainability?

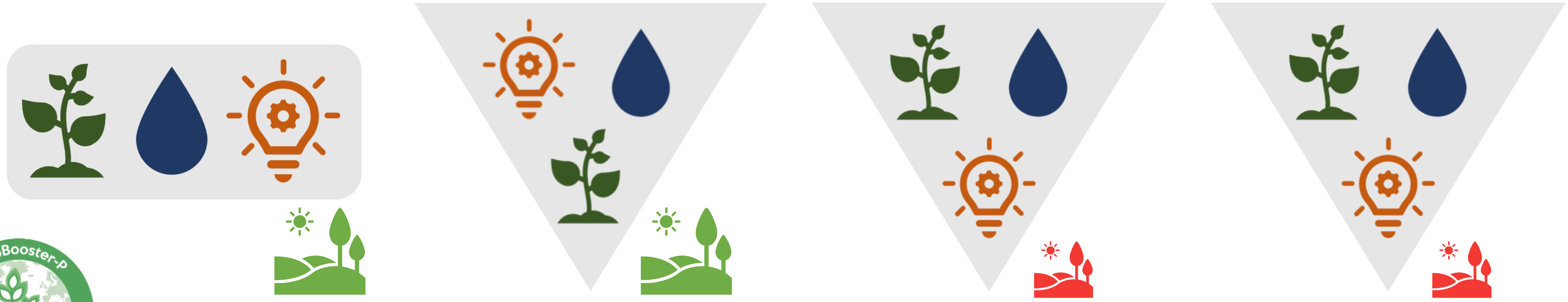
Scenario 1: Bio-Innovation

Scenario 2: My Choice

Scenario 3: Food Emergency

Scenario 4: REJECTech



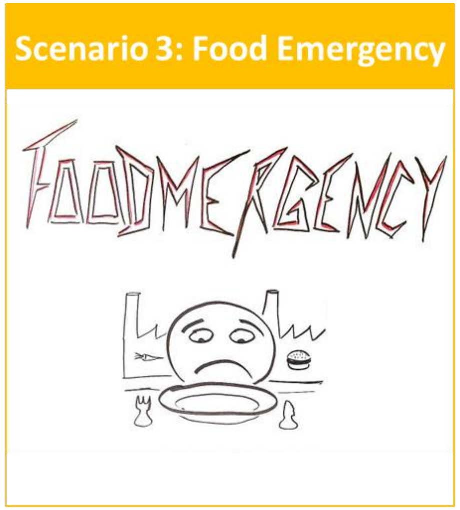


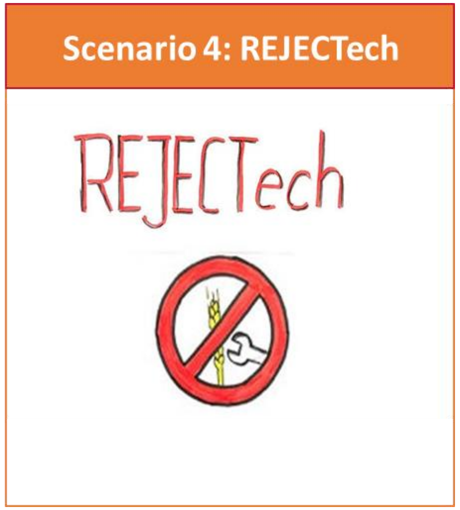
What about ENVIRONMENTAL sustainability?

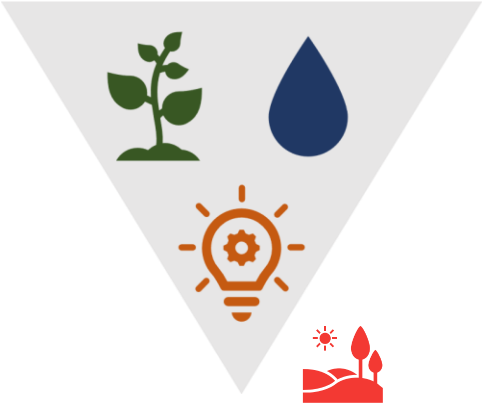
Given the time restrictions, **any solution that provides food security will be exploited**, even at the expense of (long term) environmental sustainability.

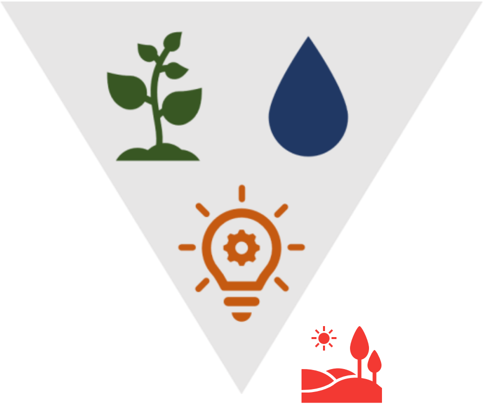
Can result in **further environmental degradation and damage** and a decreased sustainability of the agriculture, further amplifying food shortage by e.g. enhanced fertility degradation of agricultural soils, negative impacts on salt and drought stress.

Traditional agricultural practices (‘*REJECTech*’ scenario) can also **promote a more sustainable production** e.g. by including intercropping with legumes to improve N fixation.









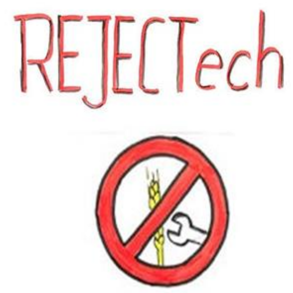
Overview: Y, S, NQ priorities

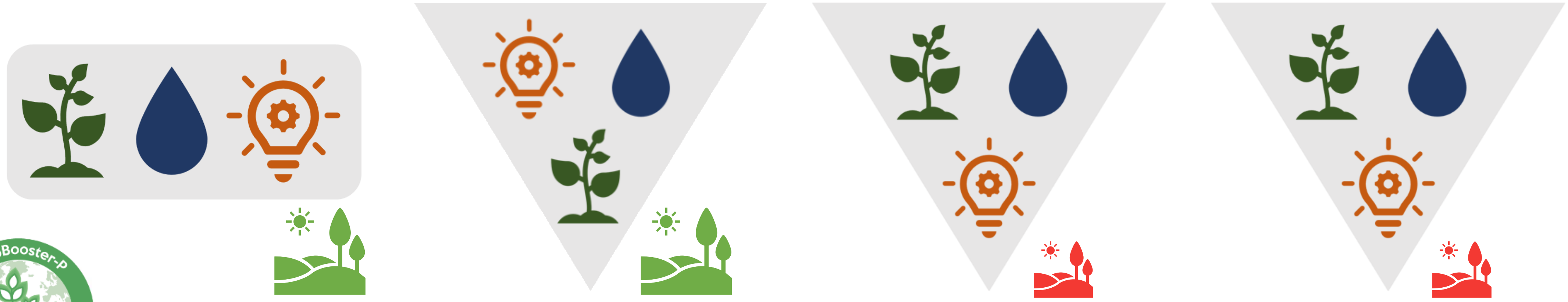
Scenario 1: Bio-Innovation

Scenario 2: My Choice

Scenario 3: Food Emergency

Scenario 4: REJECTech

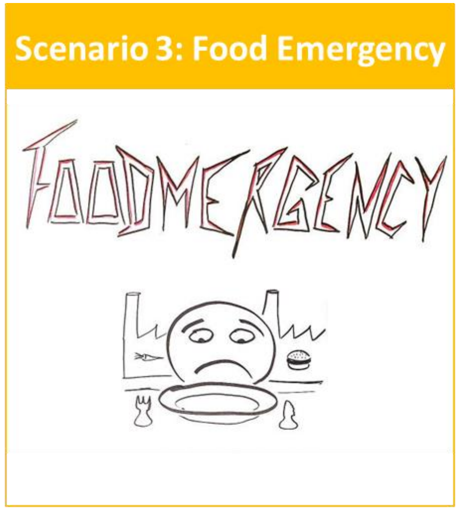


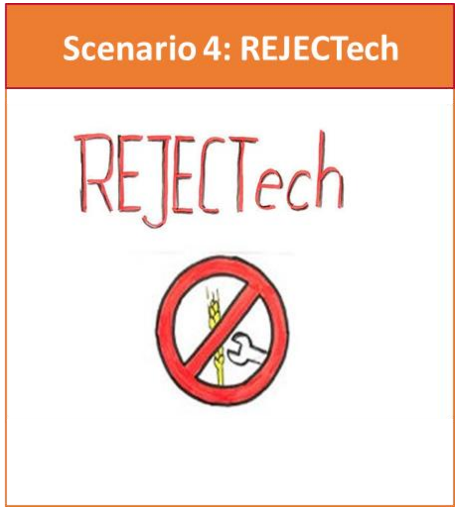


Technology acceptance as a driving force

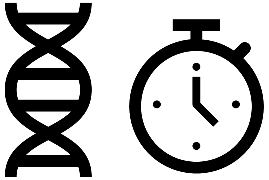
In a sense, the *‘FoodMergency’* and *‘REJECTech’* scenarios have **some similar characteristics**;

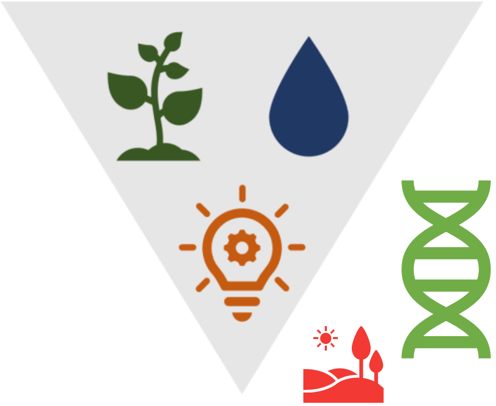
- *food shortage and endangered food security*
- *priority on Y and S improvement methods*
- *decreased priority on environmental sustainability*

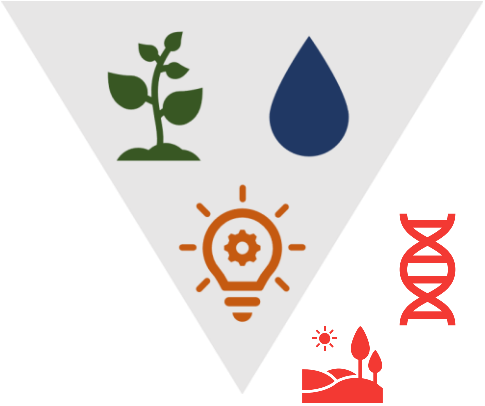




The **main difference** between the two scenarios, however, is that technical options are limited in a *‘REJECTech’* scenario, whether they are not in *‘FoodMergency’* conditions.







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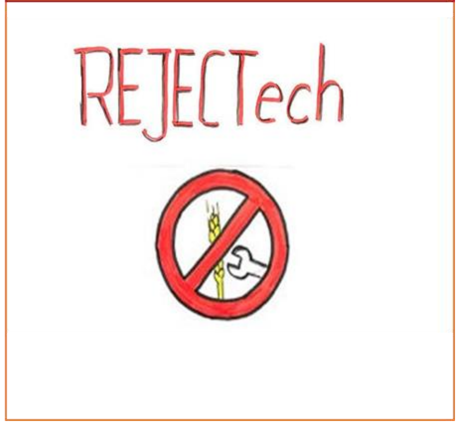
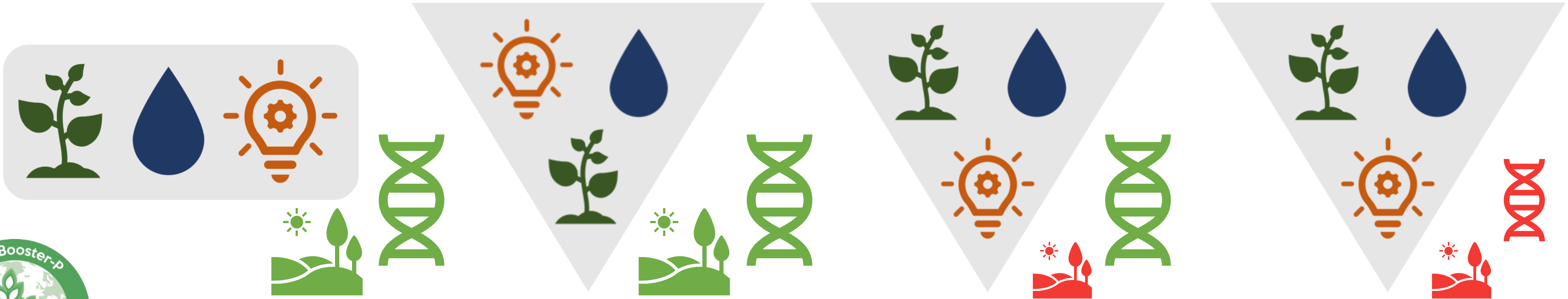
Scenario 3: Food Emergency

Scenario 4: REJECTech





What about ALTERNATIVE crop species?

Currently, **70% of the calories consumed by humans correspond to only 15 major crops** produced globally, more than half directly contributed by maize, rice, and wheat grains

With regards to neglected and underutilised crop species; '***such crops often have important nutritional, taste and other properties, or can grow in environments where other crops fail***' (FAO, 2010).

Several **constraints hindering their broader utilization**;

- a lack of priority given by local and national governments
- inadequate financial support
- lack of trained personnel
- insufficient seed or planting material
- lack of consumer demand
- legal restrictions

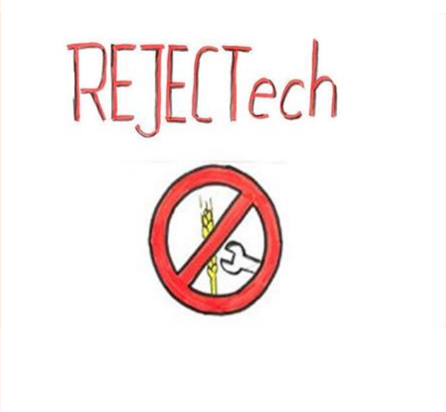
What about ALTERNATIVE crop species?

Scenario 1: Bio-Innovation

Scenario 2: My Choice

Scenario 3: Food Emergency

Scenario 4: REJECTech



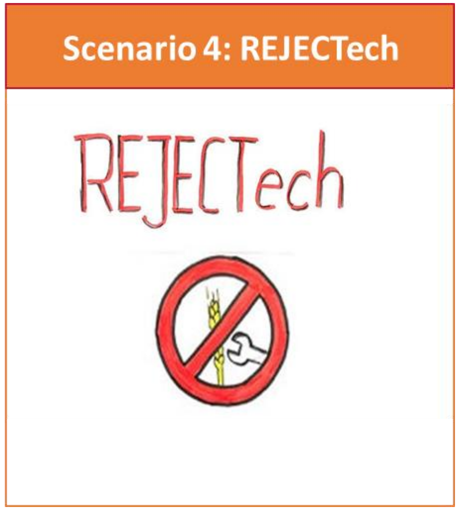
In all 4 scenarios, there is a high need to <u>investigate the wild germplasm of crops</u> which may contain the necessary variability to improve modern day varieties and to have a <u>better development of underutilized crops</u>, both terrestrial and marine species.

What about ALTERNATIVE crop species?

Of particular importance in a ***‘REJECTech’* scenario**, where we will predominantly need to rely on the currently available crops, species and germplasms:

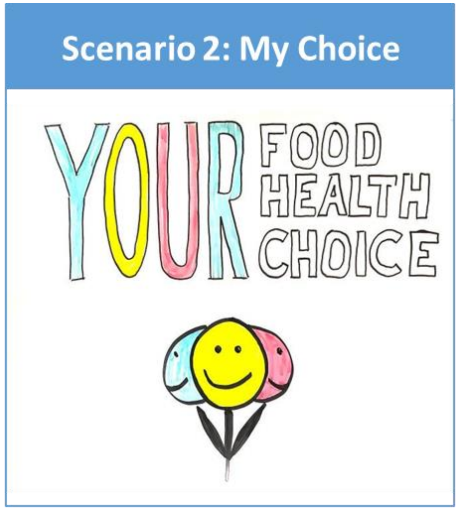
- The exploration of the genetic diversity in wild related species and the introgression of traits through traditional breeding techniques
- The development of underutilized species,

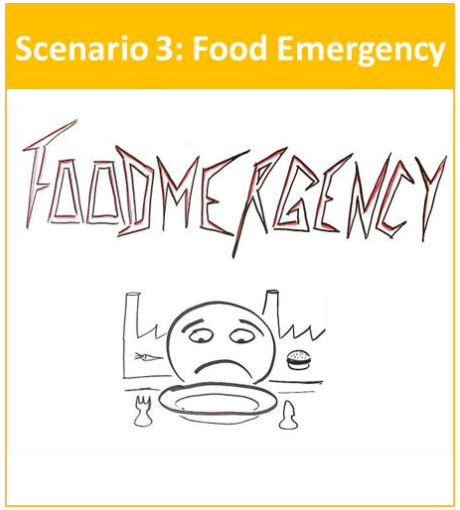
  e.g. Camelina to improve crop NQ, lupins to improve phosphorous use efficiency (PUE), and sorghum to improve drought resilience



What about ALTERNATIVE crop species?

Rapid breeding, farming and multi-purpose use of marine species.





Might require uniform production of a limited number of the most productive varieties of a few specific species

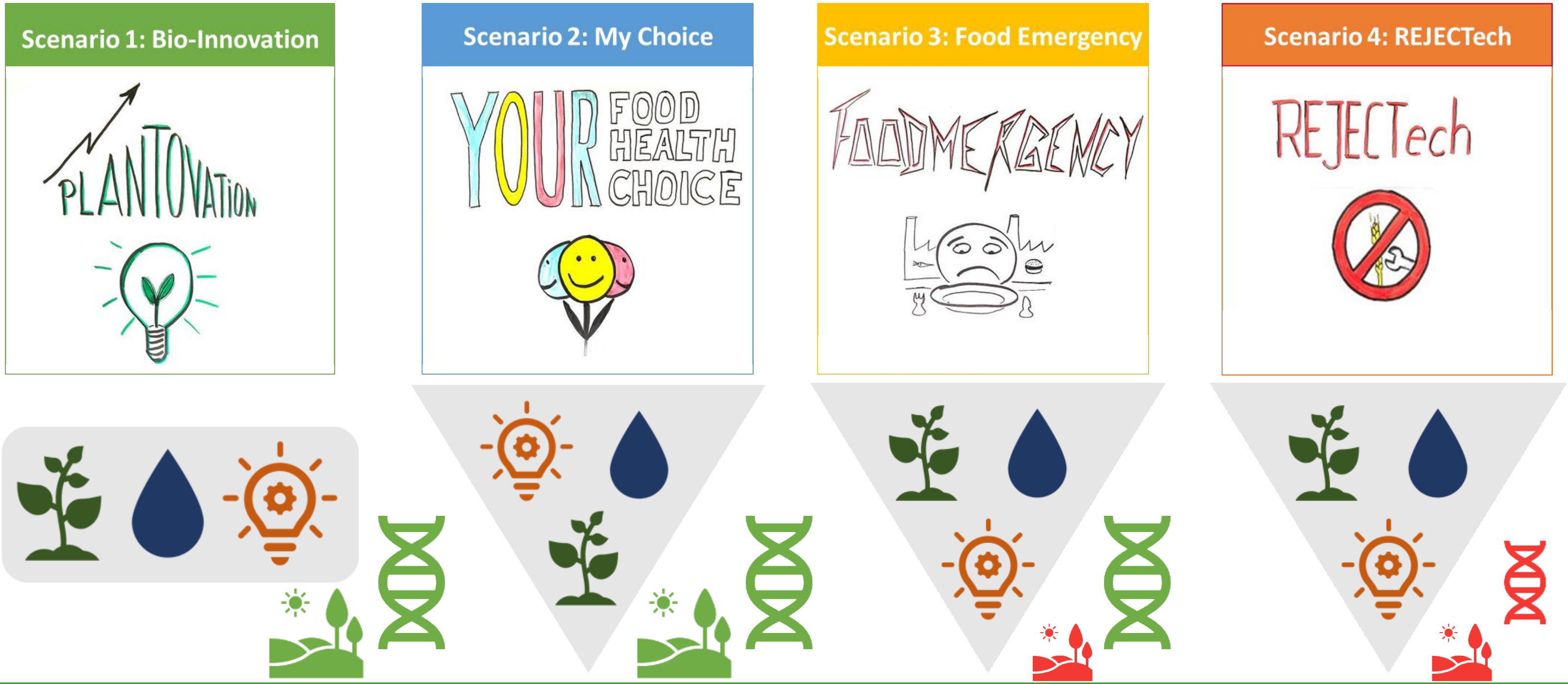
Breeding for new crops
e.g. specific breeding programs for underused and new crops that can grow in a more uncertain climate

Increased demand for personalised and alternative nutrient sources
e.g. Camelina as a plant-based source of essential fatty acids, directly in diets or via animal feed (aquaculture)

Increased demand for crops that contribute to mitigate global climate change via carbon sequestration.

Concluding Remarks

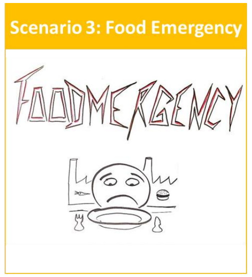
- The set of scenarios **covers a broad range of outcomes** related to major uncertainties within EU agriculture.
- Reality in the year 2050 is likely to be **a combination of aspects** from each of the four scenarios.

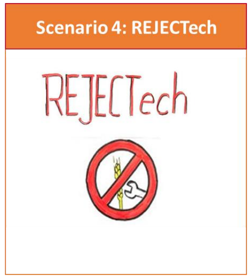


Concluding Remarks

- However, **2 major global developments** that have occurred over the past 2 years have not been taken into account when formulating these scenarios, but appear to be well-represented among the 4 scenarios:
  - the COVID-19 pandemic
  - the outbreak of war in Europe

    Note: Major effects on overall food security demonstrating the vulnerability of the global food system, showing that international trade and import of food into the European Union no longer can be taken for granted e.g. 30% of global wheat production threatened by the Ukrainian war, fossil energy prizes explode resulting in strong price increases of plant fertilizers.





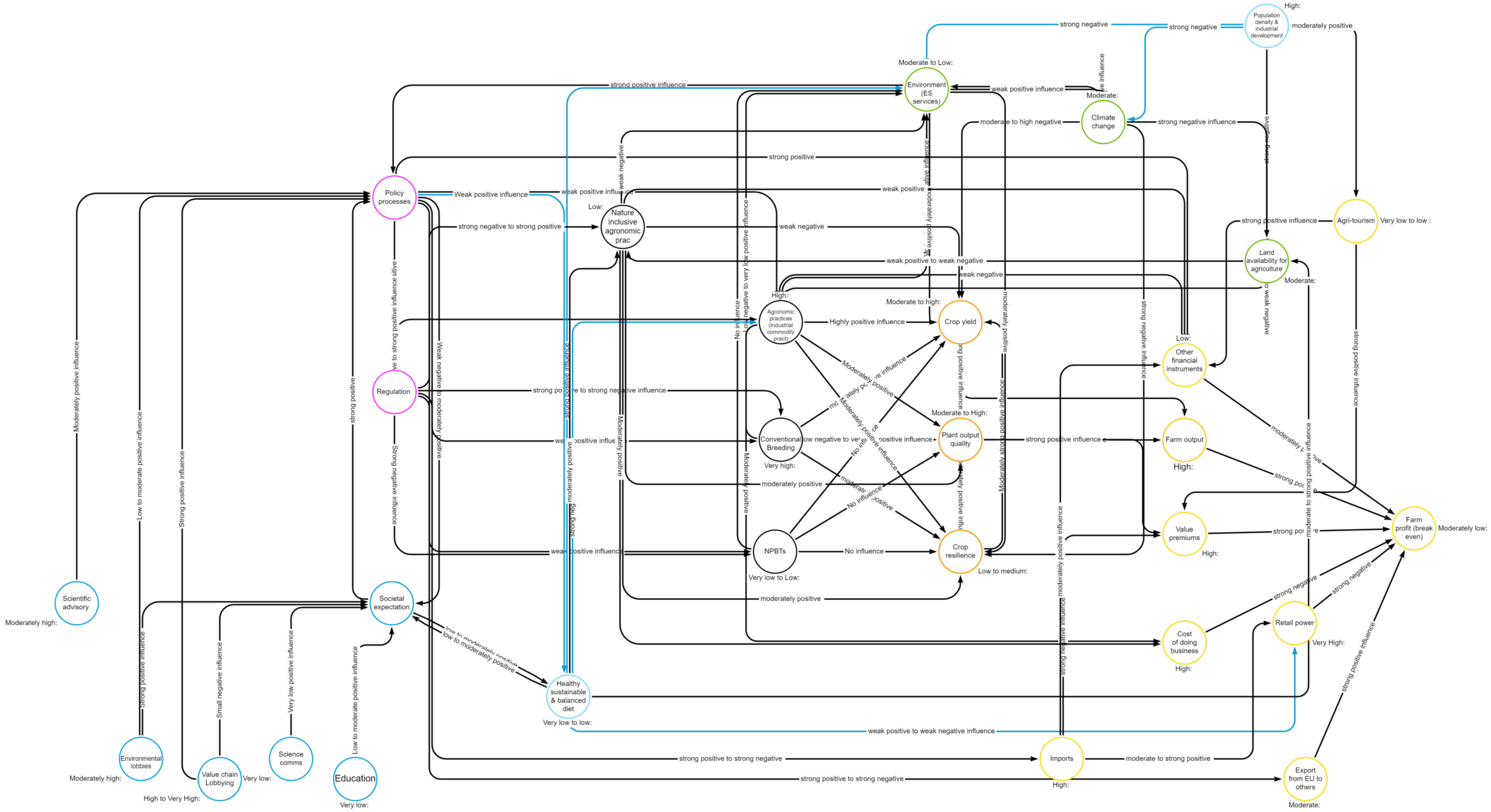
These events potentially will have MAJOR effects on the direction the future will take…

@cropbooster

CropBooster-P

European Commission

Horizon 2020
European Union funding
for Research & Innovation



Population density & industrial development
High:
moderately positive
strong negative
strong negative
Moderate to Low:
Environment (ES services)
weak positive influence
Moderate:
Climate change
moderate to high negative
strong negative influence
strong positive influence
strong positive
Policy processes
Weak positive influence
weak positive influence
weak negative
Low:
Nature inclusive agronomic prac
strong negative to strong positive
weak positive
weak negative
weak positive to weak negative
weak negative
Agri-tourism
Very low to low :
strong positive influence
Land availability for agriculture
Moderate:
High:
Agronomic practices (industrial commodity pract)
Highly positive influence
Moderate to high:
Crop yield
Low:
Other financial instruments
Regulation
strong positive to strong negative influence
Moderately positive
Moderate to High:
Plant output quality
strong positive influence
Farm output
High:
Conventional Breeding
Very high:
weak positive influence
moderately positive
No influence
Value premiums
High:
NPBTs
Very low to Low:
No influence
Crop resilience
Low to medium:
Farm profit (break even)
Moderately low:
strong positive
strong negative
Strong negative influence
Moderately positive influence
Low to moderate positive influence
Strong positive influence
Weak negative to moderately positive
strong positive
Scientific advisory
Moderately high:
Societal expectation
moderately positive
low to moderately positive
Healthy sustainable & balanced diet
Very low to low:
Cost of doing business
High:
Retail power
Very High:
weak positive to weak negative influence
Strong positive influence
Small negative influence
Very low positive influence
Low to moderate positive influence
Environmental lobbies
Moderately high:
Value chain Lobbying
High to Very High:
Very low:
Science comms
Education
Very low:
strong positive to strong negative
Imports
High:
moderate to strong positive
strong positive to strong negative
Export from EU to others
Moderate:
strong negative influence
moderately positive influence
strong positive influence
strong negative

Current states of system variables

Crop yield	*Moderate to high*
Plant quality output	*Moderate to high*
Crop resilience	*Low to moderate*
Farm output	*High*

Ecosystem services & functioning	*Low to moderate*
Climate change	*Moderate*
Agriculture land availability	*Moderate*

Value premiums	*High*
Cost of doing business	*High*
Farm profitability	*Moderately low*

Summary

- NPBTs moderately increase farm productivity and reduces agriculture’s impact on ecosystem services and functioning
- NPBTs also contribute to a very small increase in farm output, value premiums and farm profitability
- So why does it only increase farm profitability ever so slightly?
  - Does globalisation and the reducing land availability increase costs of doing business?
  - Does that much power lie with retail to suppress farm profitability?
  - Also we don’t know the influence of NPBTs in changing the influence that agronomic practices has on the cost of business?