GeneBEcon

Capturing the potential of Gene editing for a sustainable BioEconomy

System Approach Report 2 – Sil Allaert and dr. Carla Mingolla

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1. Key messages of the report

The results of the rapport are structured in two sections. In the first, a '**General systems map**' is presented. This map reflects the current "as-is" situation, where NGT-starch potatoes and other NGT crops are virtually absent in European agriculture. In the second section, the potential impact of NGTs is discussed and visualized by using **Influence diagrams**. Specifically, they show the potential impacts on conventional farmers, R&D actors and citizens.

Insights from the **General systems map**

- When discussing new genomic techniques and building sustainable futures, actors in the NGT debate should consider factors related to the **economic, ecological, social, political, and regulatory** dimensions of NGTs.
- Each factor in these 5 fields (called 'subsystems') is connected. Introducing NGTs would will impact the whole system.

Insights from **Influence diagrams:**

1. Impact of NGTs on **conventional farmers:**
    - NGTs could offer several **benefits:** It is a tool to adapt to climate change, it could improve yields, reduce pesticide and water use, and reduce costs.
    - However, several **concerns** remain: Studies researching the effects of NGTs on pesticide reduction find mixed results, and there are risks of seed price inflation due to market monopolization.
    - Important **needs** stated by farmers are: Transparency, labelling, and trace-ability to safeguard their freedom to choose whether or not to use NGT seeds.
2. Impact of NGTs on **R&D actors:**
    - NGTs could offer several **benefits**, namely faster, more precise, and more cost-effective research, also allowing smaller companies to innovate; it could foster innovation in farming R&D and strengthen European R&D's global competitiveness.
    - Again, there are several **concerns:** Risks of monopolization and inflated costs if regulations on patenting are inadequate.
    - Important **needs** stated by R&D actors are: A coherent regulatory framework that is fit for purpose.
3. Impact of NGTs on **citizens:**
    - NGTs could offer several **benefits:** NGTs could support the ambition for a sustainable bioeconomy, reducing pollution, and providing healthier, more affordable food options.
    - However, several **concerns** remain: There is uncertainty about the long-term environmental and societal impacts, and investing in NGTs might be a superficial solution that doesn't solve the structural agricultural challenges.
    - Important **needs** for citizens are: Transparency, freedom of choice, and mandatory labelling to ensure public trust and acceptance.

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2. Introduction

This report presents the current status of our analysis following the completion of two out of the three planned workshops, enriched with a literature research. We commence with a brief overview of the GeneBEcon project, followed by an explanation of the systems mapping approach and a summary of the first two workshops. Parts 3 and 4 form the core of this document, where we introduce the systems map and explore the potential impact of new genomic techniques on key stakeholders. The report concludes with a discussion of the preliminary findings and outlines the next steps.

Please note that the results presented here are part of an ongoing process, set to conclude in August 2025. As such, they are subject to further refinement as we incorporate additional perspectives and respond to emerging contextual changes during the third and final workshop on **February 24th, 2025**. If you have any questions or feedback regarding the content, we would greatly appreciate your input.

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We welcome your questions, comments and suggestions.

GeneBEcon

GeneBEcon is a Horizon Europe-funded project that is examining the innovation potential of gene editing in enabling a sustainable bioeconomy in Europe. It is running from August 2022 until August 2025. The GeneBEcon project aims to address various aspects influencing the potential uptake of NGTs. The R&I activities in the project will focus on regulatory, economic and societal aspects while improving the application of NGTs in **starch-potato** and **microalgae** as case studies. These activities are embedded by following a systems approach and the concept of Responsible Research and Innovation (RRI).

3. Systems approach

The gene editing debate is shaped by the tension between its potential to address global challenges – such as food security, climate change, and health – and concerns over ethical, societal, and environmental implications. It involves navigating regulatory frameworks that vary widely across countries, balancing innovation with safety, and addressing public trust, which is often influenced by perceptions rather than scientific consensus. The debate is further

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complicated by questions of equity, such as who benefits from the technology, and broader philosophical considerations about human intervention in natural processes.

Systems thinking could support this debate, as it aids in integrating diverse perspectives, assessing interconnected impacts, and designing holistic solutions that align with societal values and long-term goals.

In contrast to linear thinking, which typically examines singular components in isolation, systems thinking emphasizes the relationships between elements in a system (Monat & Gannon, 2015). Linear thinking often oversimplifies these relationships, possibly leading to unintended consequences. Systems thinking, by contrast, acknowledges that systems are dynamic and shaped by both stabilizing and destabilizing forces, as well as feedback mechanisms. For example, introducing gene-edited, drought-resistant starch potatoes into the European agricultural system would not simply increase yields for a single farmer. It could also affect the demand for crops from neighboring farms that do not use NGTs and it may lead to social backlash if public acceptance of NGTs is low. It's important to note that systems thinking does not replace traditional analytical research; rather, it should be seen as complementary.

Systems thinking uses a specific language (Monat & Gannon, 2015). Therefore, in this report, we will frequently refer to *perspectives*, *elements*, *boundaries*, *subsystems*, and *levels*. A fundamental concept in systems thinking is that it incorporates multiple **perspectives** to gain a holistic understanding of the various system parts (Cabrera, 2006). This process typically includes involving stakeholders who can share specialized knowledge and viewpoints. We are integrating this idea by organizing three workshops with a variety of stakeholders.

Furtermore, systems thinking emphasizes the relationships between **elements** (Monat & Gannon, 2015). Elements, also known as components, variables, or factors (with slight semantic distinctions), refer to individual parts within a system. Elements can be tangible, such as people, infrastructure, or crops, or intangible, like rules, processes, or beliefs. Their interactions collectively shape the system's behavior and outcomes. In this report, elements will refer to tangible and intangible parts significant to the European bioeconomy, such as specific legislation, farming practices, and consumer behavior.

To apply systems thinking, researchers define the system under study by establishing its **boundaries** (Haraldsson, 2000; Wright & Meadows, 2008). However, boundary-setting can be challenging since everything connects to something else, and systems often lack clear boundaries. Where, for instance, does a forest end and a prairie begin? Similarly, defining the boundary of the European bioeconomy for GeneBEcon involves arbitrary decisions, given our globalized world.

Systems are composed of **subsystems** in which elements are closely related. The world organizes itself into different layers of subsystems, each nested within a larger one (Wright & Meadows, 2008). A cell operates through the relationships between its parts while forming part of an organ with other cells, and this organ belongs to a broader organism, a family, and so forth. This arrangement, known as a hierarchy, consists of systems and subsystems organized across **levels**. For clarity, we have defined our subsystems broadly in the systems maps presented below. As a result, elements within the same subsystem may occupy different levels. For example, both *culture* (reaching every citizen) and *consumer behavior* (here defined as individual choices) are part of the social subsystem. To distinguish these, they are represented at different levels in our visualization to better clarify their roles.

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4. Workshop methodology

Systems thinking, an approach to understand wicked problems, is important for the GeneBEcon project. The ongoing debate about genetically modified organisms (GMOs) and new genomic technique is often polarized, with little bridges between the different perspectives. In a series of three workshops (2023, 2024, 2025), we strive to understand the complex interrelationships between social, regulatory, political, economic, and environmental factors that influence the debate about and development of new genomic techniques. The production systems of starch-potatoes and microalgae are used as case-studies to make discussions tangible. By taking a holistic approach to understand these interconnections, we hope to identify potential (unintended) consequences, benefits and risks of gene editing. This way of thinking is visualized in a **systems map**. It helps to illustrate the relationships and interactions between various components within a system and provides a holistic view of the system, highlighting connections, feedback loops and dependencies to help understand its structure and dynamics.

Importantly, during the workshops, we actively aim to create a ground in which all perspectives are heard in an equal and safe setting. Although not easy, we aspire to take a neutral position in our system approach in which many different opinions are included. We hope this approach constitutes understanding and learning on the issue at hand, and helps to build bridges between different perspectives.

First workshop

On March 1st, 2023, the first system mapping workshop was organized in Brussels. Prior to the workshop, desk research and interviews were done to develop an actor map, value chains and relevant subsystems[1] for the topic at hand. These were used as a starting point for the discussions during the workshop.

We involved a broad spectrum of stakeholders with different viewpoints. Ultimately, 32 persons attended (excluding six moderators). 18 of those were external to GeneBEcon. These were mainly from research, policy and business. The day was divided into three parts, each introduced by a presentation to provide the necessary background information. All discussions took place in two groups: one focusing on the starch potato case of the project, the other on the microalgae case.

In the first part of the workshop, the participants – divided into small break out groups – discussed the system "as it is now" ('as is'). Starting from the three subsystems (ecological, regulatory and socio-economic), participants were asked to detect the relevant elements within each of these subsystems. During these discussions, the moderators actively collected the input. As a result, several draft system maps were created. The second part focused on the impact of introducing NGTs in the different systems. Participants reflected on the question: which elements of the system 'as is' could be influenced by NGT's? The potential impacts could be positive, negative, neutral or unpredictable. In the last part of the workshop, the participants further discussed on the potential impacts of NGTs: how exactly would NGTs influence the elements of the system 'as is'? To answer this question, different scenarios within the EU regulatory framework of GMOs/NGTs were taken into account.

[1] Three subsystems were identified: the ecological subsystem, the regulatory subsystem and the socio-economic subsystem

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Results of the first workshop

After the workshop, the input was analyzed, and two systems maps were developed: one for the starch potato case and one for the microalgae case. The maps can be found in the appendix of this report. In the first report, we explained these maps in detail. Furthermore, the report was shared with the participants of the first workshop for feedback. A summary was also published on the GeneBEcon website and can be accessed via this link. In summary, the report highlights that introducing NGT-derived organisms into the European bioeconomy involves numerous interconnected factors, which can be grouped into four key subsystems: Economic, Ecological, Social, and Regulatory. Additionally, the report stresses that everything is connected. Elements influence each other within groups, as well as between subsystems. When one element changes, this will impact the whole system.

Figure 1: Plenary introduction on March 1st, 2023

Second workshop

The second Systems Mapping workshop took place on April 17, 2024. Further refining the approach, we focused on including perspectives that had not yet been represented, particularly those more critical of new genomic techniques. To foster a constructive and accessible environment, we aimed for a small workshop with a maximum of 20 participants. Ultimately, 12 people attended, including six external stakeholders, primarily from social science backgrounds, with professional expertise in research, food safety, organic food, and food-citizen relations.

Figure 2: Introduction on April 17th, 2024

The workshop focused solely on the starch potato case, as the European Commission's proposal for a new regulation on NGT plants, published on July 5, 2023, did not include microalgae.

The workshop followed a three-part structure. In the first part, participants engaged in an in-depth discussion of the starch potato systems map from the first systems workshop, providing valuable feedback. The second part explored the potential impacts of NGTs on this case. The final part delved further into these impacts, taking into account the new NGT regulation proposal.

Results of the second workshop

After the second workshop, we analyzed the input and feedback that was given by the participants. In summary, the feedback focused on a) the visualization of the systems maps, b) the political elements in the system, and c) specific elements and interrelations that needed further improvement.

The first point on visualization was multi-faceted. Participants agreed that the initial systems map appeared overly complex. Additionally, certain elements in the map were identified as having a higher “level” of influence, impacting the entire system rather than specific components. For instance, in the original starch potato production system map, climate change was only affecting four elements. Participants suggested, however, that climate change has such broad significance that it should be depicted as influencing the majority (if not all) of the map's elements. Furthermore, complexity was further increased by the inclusion of *factors* and *actors* in the same map without clear differentiation.

Second, participants expressed the need for a distinct subsystem to address political factors. Given the political nature of the NGT debate, it was suggested that multiple elements might be better positioned within a political subsystem. Lastly, specific elements and interrelationships were modified or added.

The development of the systems map followed an iterative approach with a set of validation steps. Feedback from the workshops was integrated through experimentation with various new visual representations of the starch potato systems map. For instance, “levels” in the system were first visualized by categorizing elements into a macro, meso, and micro framework, which then evolved into a Multi-level systems model, ultimately leading to the current map which can be found in section 6.

The following sections of this report present a general systems map of the starch potato production system, and several influence diagrams where the impact of NGTs on several specific actors is discussed. The findings are provisional, as the final workshop in February 2025 will be used for feedback and improvement. In this report, the results are based on the first two workshops, as well as a review of relevant literature.

General starch potato systems map and impact of NGTs on specific actors

We will first present the **general systems map** of the starch potato production system in the European Union**.** This map should visualize the elements that are important in the production, processing and consumption of starch potatoes. The general systems map is **framed from the European debate of the potential impact of new genomic techniques**. In this sense, it includes elements like ‘Proposal for new regulation on NGT plants’, ‘Opinions of EU member states towards NGTs’, and others. The general systems map reflects the current “**as-is**” situation, where NGT potatoes and other NGT crops are virtually absent in European bioeconomy. Here, “current” refers to the period during which this map was developed, from mid-2023 through late 2024. Given the evolving nature of the gene-editing debate in the EU, further changes in this landscape (and the maps) are expected.

Furthermore, the general systems map was constructed based on the starch potato case in GeneBEcon to make the discussions tangible. However, most, if not all, of the elements in the map are also applicable to the production of other (NGT) crops. Finally, although the boundary of our systems map is the European Union, we acknowledge that international NGT

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developments from outside of the EU will have an important impact on the debate within the EU.

After presenting the general systems map, section 7 delves into the benefits and risks of NGTs by looking at the **specific impact that NGTs could have on three stakeholder groups: conventional farmers, R&D actors and citizens**. This is visualized in three influence diagrams, illustrating the potential direct and indirect impacts of introducing NGTs. All three diagrams will be explained in further detail. The maps are based on the discussions during both workshops, further enriched by scientific papers (Crossland-Marr et al., 2023; Fischer & Rock, 2023; Siebert et al., 2022), reports by advocates and critics (Belderok, 2021; Robinson, 2021), and news articles (Bounds & Terazono, 2022; Van Dyck & Kenis, 2023).

The draft general systems map and the three influence diagrams were shared with the GeneBEcon project partners for review in October 2024. Several of their comments were subsequently integrated in this report.

5. Mapping methodology

General systems map methodology

The development of the systems map followed an iterative approach. After the second workshop, the feedback was integrated through experimentation with various new visual representations of the starch potato systems map. These experimentations were inspired by the systems theories: 'The Iceberg Model' (Cabrera, 2006; Guynn et al., 2022) and 'The Multi-Level Perspective' (Geels, 2019) and the theory of micro-, meso- and macro levels (Bronfenbrenner, 1977).

The elements in the systems map were categorized into subsystems (economic, ecological, social, political and regulatory) and levels (business/individual, food system, landscape) based on input from the workshop and a review of relevant literature. Subsequently, the researchers utilized the GenAI tool 'ChatGPT' to cross-check how the tool would categorize the elements across the different levels. Overall, 68% of the elements were categorized identically by both the researchers and ChatGPT. For the elements where discrepancies arose, additional literature was considered for further analysis. Based on this review, some elements were reclassified according to ChatGPT's suggestions, while others were retained in their original categories as determined by the researchers.

Influence diagrams methodology

In Section 7 of the report, we examine the potential impact of introducing new genomic techniques on starch potato production within the European bioeconomy. Following the proposal for a new regulation on NGT plants, these would be NGTs in category 1, defined by the EC as plants "that could occur naturally or by conventional breeding" (European Commission, 2023a). Given that the NGT debate involves numerous stakeholders, each often emphasizing different arguments (pro, contra and neutral), we address these impacts focusing on multiple different stakeholder groups. In this report, we will cover three key actors in the debate: 'Conventional farmers', 'R&D actors' and 'Citizens', by visualizing and discussing the impact that NGTs would have on these groups. In the final report in 2025, we will expand our analysis by discussing other key stakeholders in the debate. The selection of conventional farmers, R&D actors and citizens as focal groups stems from the workshops, where these three actors emerged most prominently.

In both workshops, participants considered and evaluated the potential (neutral, positive and negative) consequences of NGTs to those groups. This input was synthetized into a list of general impacts, further expanded using scientific literature (Crossland-Marr et al., 2023; Fischer & Rock, 2023; Siebert et al., 2022), reports by advocates and critics (Belderok, 2021; Robinson, 2021), and news articles (Bounds & Terazono, 2022; Van Dyck & Kenis, 2023).

From this list, we identified which specific impacts were most relevant to each actor group. While some impacts were unique to a single group, others were relevant to multiple stakeholders. Although other groups—such as organic farmers or policymakers—are also affected by NGTs, the choice to focus on conventional farmers, R&D actors, and citizens is particularly effective for this report. These groups not only emerged as the most pronounced during the workshops but also represent distinct and non-overlapping perspectives regarding the effects of NGTs. This allows for the development of the most comprehensive and detailed influence diagrams at this stage.

In the following paragraphs, the elements of each subsystem in the general systems map will be explained.

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6. Systems map of starch potato production in European bioeconomy

Reading guide of the general systems map

Conforming to the focus of GeneBEcon, the focus of the general systems map is the case study of starch potatoes[2]. The map consists of **elements** that would be **important in the production system of starch potatoes** and is **framed from the European debate of the potential impact of new genomic techniques**. Therefore, there are elements relating to the production of any kind of starch potato, while other elements relate to the NGT aspect of the production. The map consists of factors, levels, subsystems, and actors.

The factors represent key **elements** within the five subsystems that significantly influence the bioeconomy of starch potatoes in Europe.

When analyzing the elements, we noticed that they could be classified into different system levels. Therefore, surrounding the core, three concentric circles represent the **system levels.** The **Business/Individual level** encompasses all elements directly and concretely connected to individual entities, such as farms, citizens or starch processing companies. The **Food System level[3]** includes the processes, regulations, and structures involved in the production of (NGT-derived) starch potatoes. These elements significantly influence individual actors, yet are largely beyond their control. Finally, the **Landscape level[4]** comprises global-scale factors that affect both the Food System and the Business/Individual levels. Individual actors (e.g. farmers, seed companies) and elements in the Food system level have a marginal or no influence over elements at this level.

The elements in all levels are categorized in five **subsystems**. These subsystems are all interconnected, which is visualized by the overlapping areas. The **economic subsystem** involves market forces, costs, income, and competition within starch potato production. The **social subsystem** relates to public opinion, consumer behavior, and cultural values. The **political subsystem** includes the influence of political actors and advocacy groups, with EU member state support and political debates shaping the regulatory environment for NGTs. The **regulatory subsystem** covers the laws and policies that directly or indirectly relate to the production and marketing of (NGT-derived) starch potatoes. Lastly, the **ecological subsystem** focuses on environmental factors in the production of starch potatoes.

Finally, the systems map shows several **stakeholders** next to the outer system level. This implies that several stakeholders impact, and would be impacted by, the production of NGT-derived starch potatoes. The relevant stakeholder groups that we identified are conventional farmers[5], organic farmers, EU-level entities (such as EFSA), civil society organizations, citizens, EU member states, value chain actors and scientists. This selection emerged from the workshops, but is not exhaustive.

[2] We decided to only focus on the starch potatoes and not on the microalgae case because algae or not considered in the new regulatory proposal on plants produced by NGTs, published July 5th, 2023. Focusing on NGT-derived potatoes makes the discussions more tangible.
[3] The Food System level was inspired by the regime level in the Multi-Level Perspective (Geels, 2019).
[4] The Landscape level was inspired by the landscape level in the Multi-Level Perspective (Geels, 2019).
[5] 'Conventional' is – because of a lack of a better term – used to make the differentiation with organic farmers, which happens frequently in literature (Mccann et al., 1997; Uematsu & Mishra, 2012). We acknowledge that there are a lot of differences in conventional farming practices.

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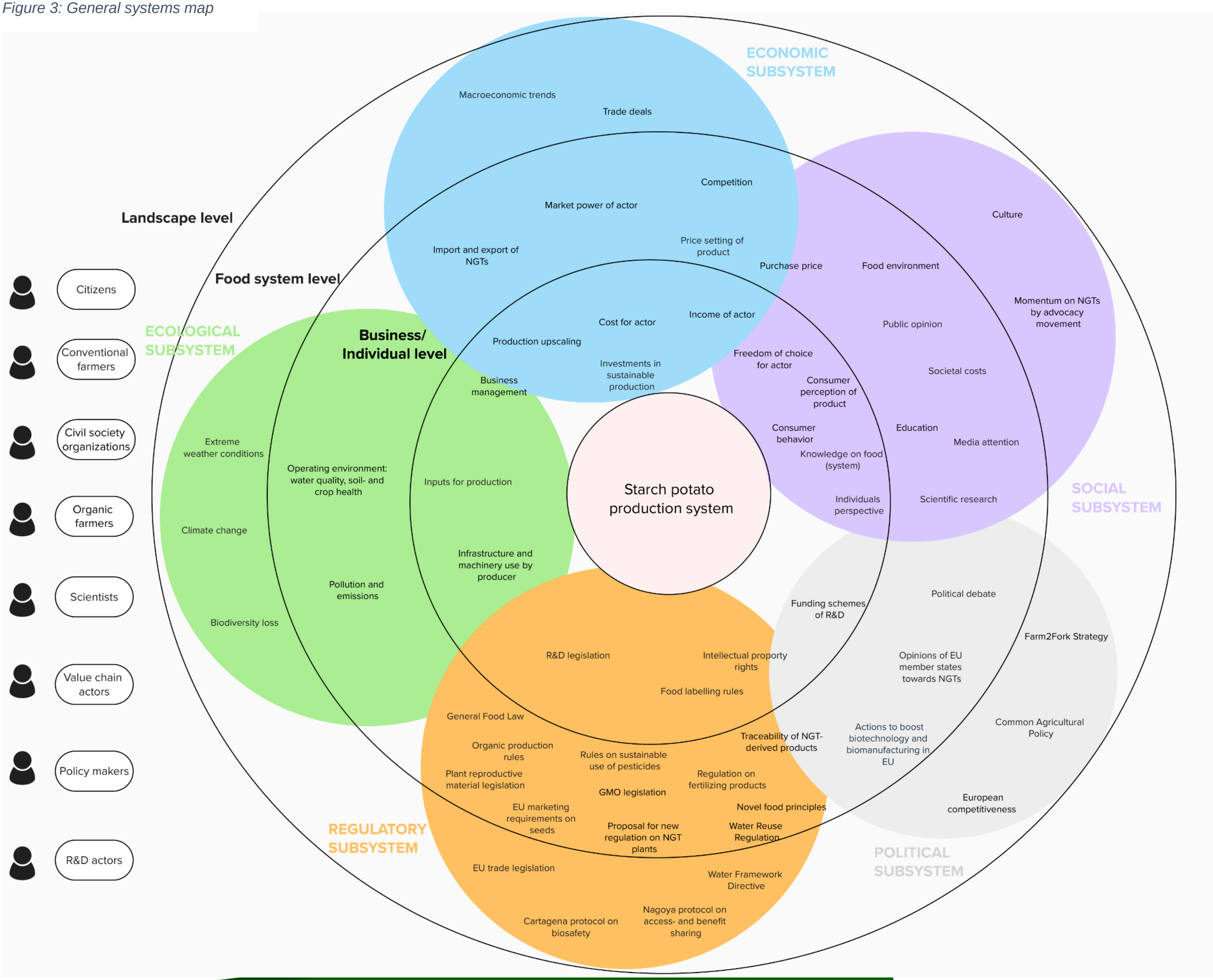
Figure 3: General systems map



Deep dive

Economic subsystem

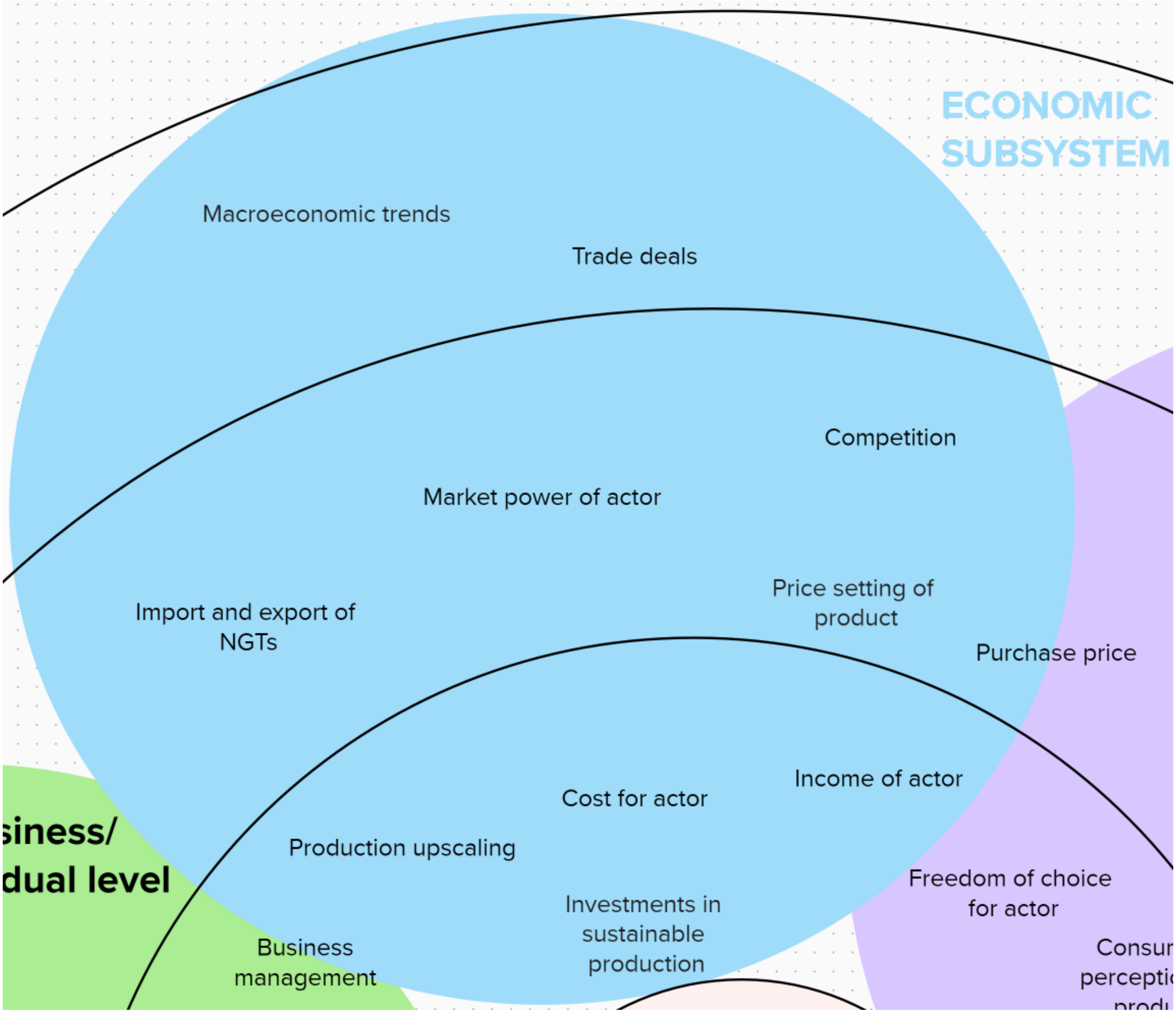


Figure 4: Economic subsystem of the general systems map

At the **Business/Individual level** of the economic subsystem, elements such as investments in sustainable production, the need for production upscaling, costs for actors, and their income shape the financial decisions and outcomes of individual actors. Costs and incomes are closely tied to business management (which also impact ecological elements), as they directly result from individual decisions, making them integral to this level. Similarly, **investing in sustainable practices** or **production upscaling** represent individual strategic choices influenced by market trends at higher levels, often involving short-term costs but offering long-term benefits.

As individual economic activities scale up, they interact with systemic forces at the **Food System level**. For example, the division of **market power** between **actors** can influence smaller-scale actors, affecting their negotiating power and access to markets. **Competition** between actors within the food system further shapes market dynamics. Meanwhile, the **price setting of products**, influenced by both supply and demand, determines profitability for all

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individual actors in the value chain. Finally, the global trade of NGT crops is also part of this level. Although NGT trade in the EU is currently limited, widespread **import and export** could have significant effects on the EU food system as a whole. For example, an increasing import of GM soy would affect the reliance of EU livestock farmers on regular soy, therefore influencing the broader production (f.e. purchase prices of feed) and consumption (f.e. acceptance) of livestock farming (Basnet et al., 2023).

At the **Landscape level**, overarching factors such as **trade deals** and **macroeconomic trends** exert a top-down influence on the economic subsystem. For instance, international trade agreements shape the regulatory and economic environment for exporting NGT-derived products. Similarly, macroeconomic trends, such as the European energy inflation of 2022create economic conditions that impact all levels of the subsystem. These landscape-level forces are largely beyond the control of individual actors and the elements in the food system.

Social subsystem

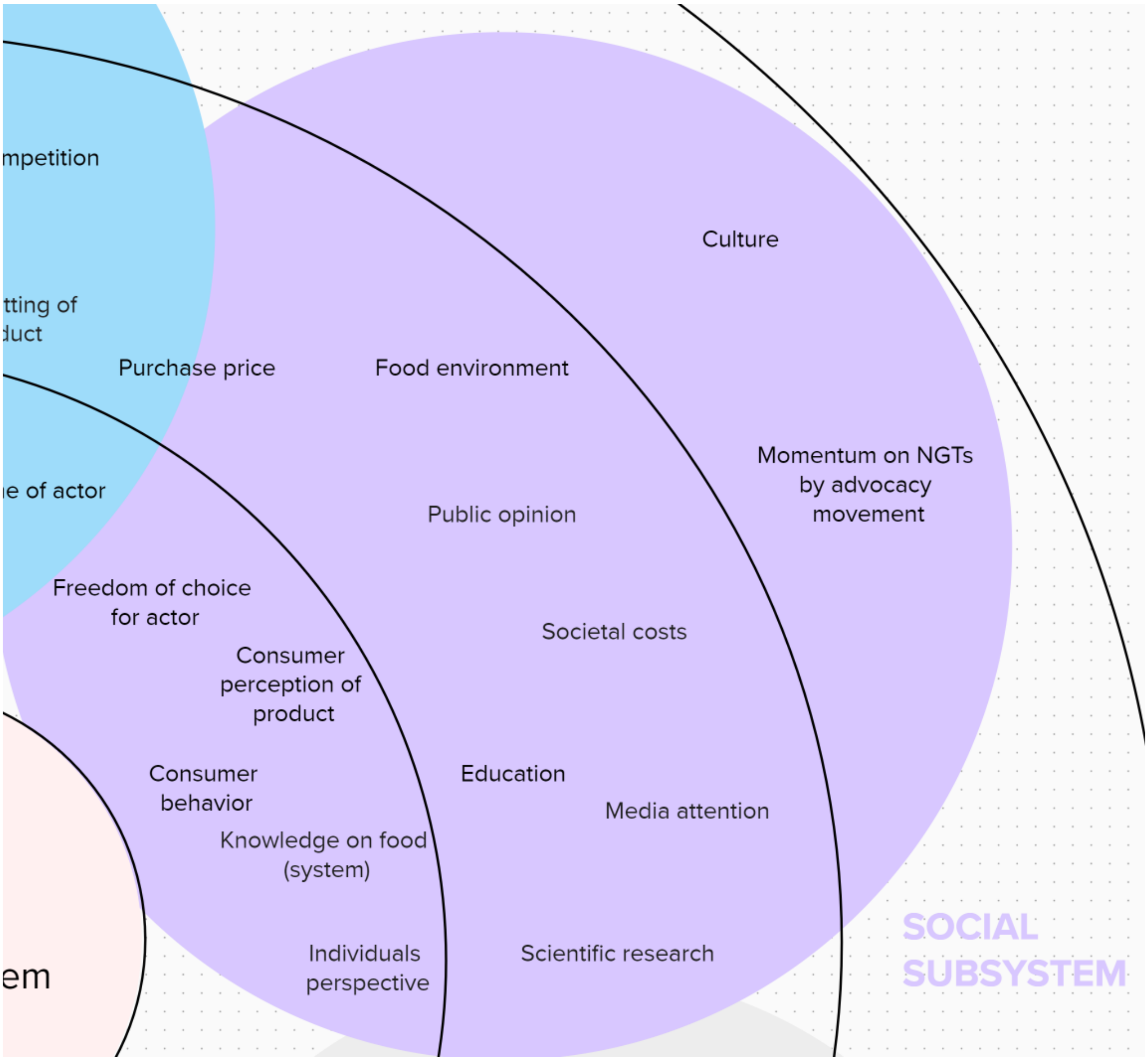

Figure 5: Social subsystem of the general systems map

The **social subsystem** relates to the knowledge, the choices of actors and the values on (NGT) agricultural products. At the **Business/Individual level**, the factors relate to the individual actors. Every actor within the starch potato production system – be it citizens, farmers, businesses, or others – has the **freedom to choose** whether to use or consume (NGT) starch potatoes, or to abstain from their use entirely. This is based on their **knowledge** of the product, their own values and **perspective** and their individual **perception** of quality or taste of the product. However, studies reveal that consumers often act differently from their stated values and general perceptions of a product, with their actual **behavior** and product choices frequently diverging from their broader perspectives (Font-i-Furnols & Guerrero, 2014).

At the **Food System level**, factors such as purchase price, food environment, public opinion, education, media attention, scientific research and societal costs create broader social contexts that shape individual perception and decisions. Among these, research consistently identifies **purchase price** as a key determinant of individual choices (Font-i-Furnols &

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Guerrero, 2014). This influence extends to NGT products, as demonstrated by GeneBEcon research (Pokrivcak et al., 2024). Another important factor is the **food environment**, which can be understood as the physical, economic, political, and sociocultural context in which citizens engage with the food system (Fischer & Rock, 2023; Van Dyck & Kenis, 2023). It is a broad concept that includes the proximity to, and affordability of, healthy food, food quality and safety, and information of food (including promotion and advertisements).

Public opinion is a particularly relevant element in the case of GMOs and NGTs. A pronounced public opinion has a significant impact on the behavior of, for instance, policy makers, citizens and businesses, as history has shown in the case of GMOs (Strobbe et al., 2023). Closely related to this is the **media attention,** which is a well-documented factor with a significant influence on public opinion (McCombs, 2002). Furthermore, **education** is crucial in fostering understanding and addressing misconceptions about food production and processing (Sutherland et al., 2020). A growing lack of knowledge by citizens, policy makers and business on food and agriculture underscores the importance of proper education, organized on a food-system level, on this topic (Regan & Kenny, 2022; Sutherland et al., 2020). **Scientific research** is another element in the Food System level. It borders the political subsystem as it depends of (often politically driven) research funding, but also shapes policy and society (Breithaupt, 2004; Payne, 2003). Finally, **societal costs**, including public health implications from pollution, further influence the acceptance of new production and processing practices.

At the **Landscape level**, **advocacy movements** can build or hinder momentum of innovations, shaping policies, media attention and public attitudes (Bain & Dandachi, 2014). These movements are part of larger societal shifts and operate beyond the control of individual actors or the food system. Meanwhile, **cultural values** and traditions deeply influence how societies perceive and integrate innovations like GMOs and NGTs into their food systems. For example, cultural preferences for “natural” agricultural practices may limit the acceptance of genetically edited crops (Turnbull et al., 2021). These values are deeply rooted in food systems and significantly influence individual actors.

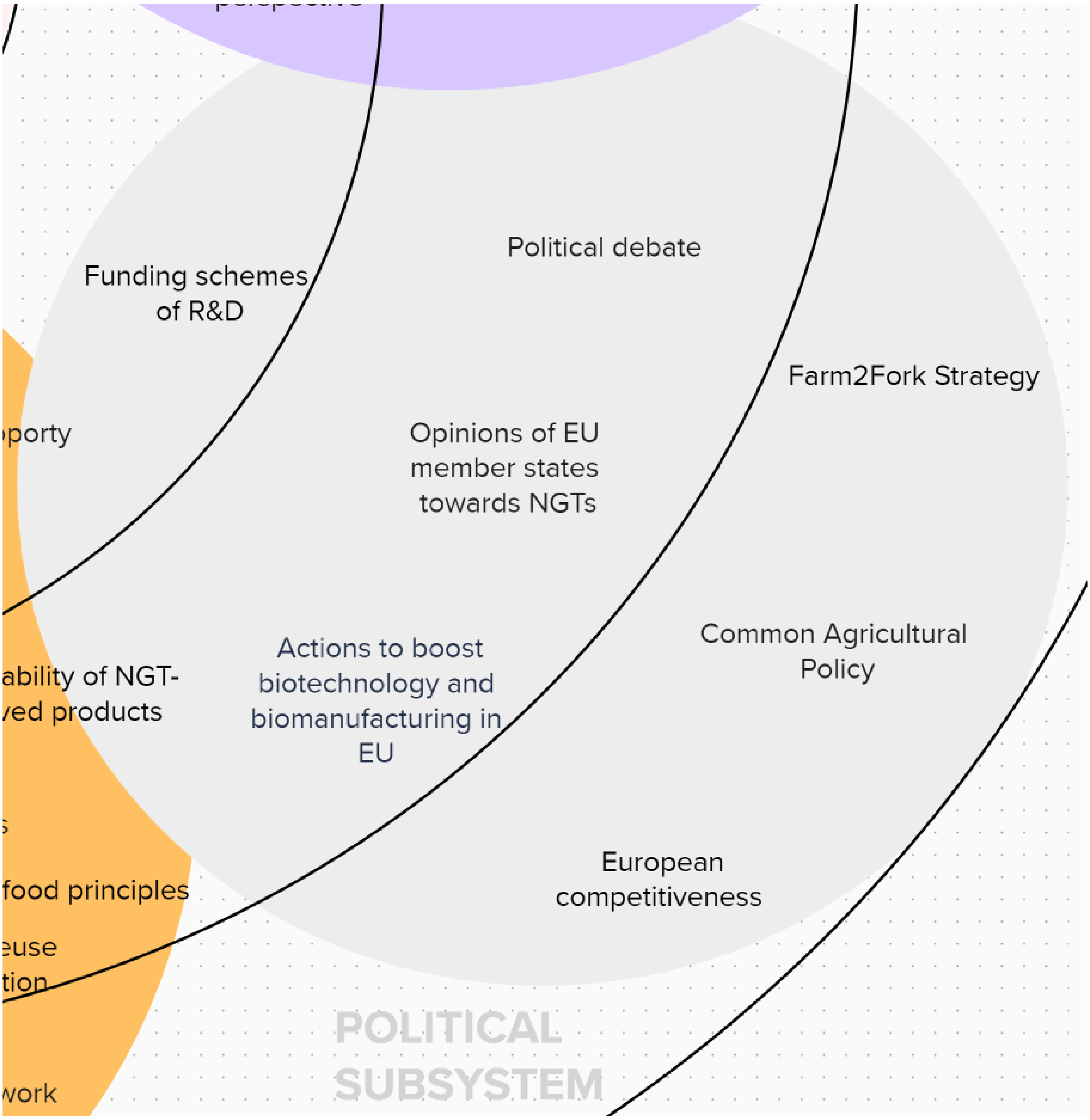

Figure 6: Poitical subsystem of the general systems map

The political subsystem includes the elements influenced by actors shaping EU policy.

Only one element is categorized in the business/individual level of the subsystem, which is **Funding schemes of Research and Development.** These are directly relevant to individual entities, such as research institutions and biotech companies, as funding schemes support their activities. As such, funding schemes enable innovation at the business level rather than system-wide regulation.

Most of the elements in the political subsystem are categorized in the levels of the food system and the landscape. In the food system level, there are the political debate, the opinions of EU member states towards NGTs, and the Actions to boost biotechnology and biomanufacturing in the European Union. The **political debate** refers to the general discourse and policy considerations that are surrounding topics in the European bioeconomy, such as the sustainable production or New Genomic Techniques. Although individual actors are influenced by the outcomes, the debate itself operates at a systemic level, shaping the overall regulatory and operational environment. Second, **opinions of EU Member states** influence regulatory stances and policy implementation within the EU's food system. These collective views shape the general landscape of acceptance and integration of innovations like NGTs, impacting the food system level rather than specific businesses. Finally, the European Commission proposed a series of targeted **actions to boost biotechnology and biomanufacturing in the EU** in March of 2024 (European Commission, 2024a). These affect the EU's bioeconomy and agricultural sector as a whole rather than targeting individual actors.

On the level of the landscape are the elements: Farm2Fork strategy, Common Agricultural Policy (CAP) and European Competitiveness. The **Farm2Fork strategy** is designed to steer the entire EU food system towards sustainability goals, which impacts everything from production methods to consumption trends. Although it influences specific practices within the food system – and could therefore also fit in the Food System level -, it sets broad policy goals that shape how the EU envisions its future bioeconomy. The same argumentation can be used when categorizing the **Common Agricultural Policy**. The CAP shapes European agriculture and provides strategic direction that individual actors and the food system as a whole must adapt to over time. This makes it fitting as a driver of trends and goals at the Landscape level. Lastly, **Europe's competitiveness** is a macro-level consideration that influences policy decisions impacting the EU's position in the global economy. This is especially relevant in the case of new genomic techniques, as there are regions in the world where the research and development for NGTs is subject to a more flexible regulation (Jorasch, 2020).

Regulatory subsystem

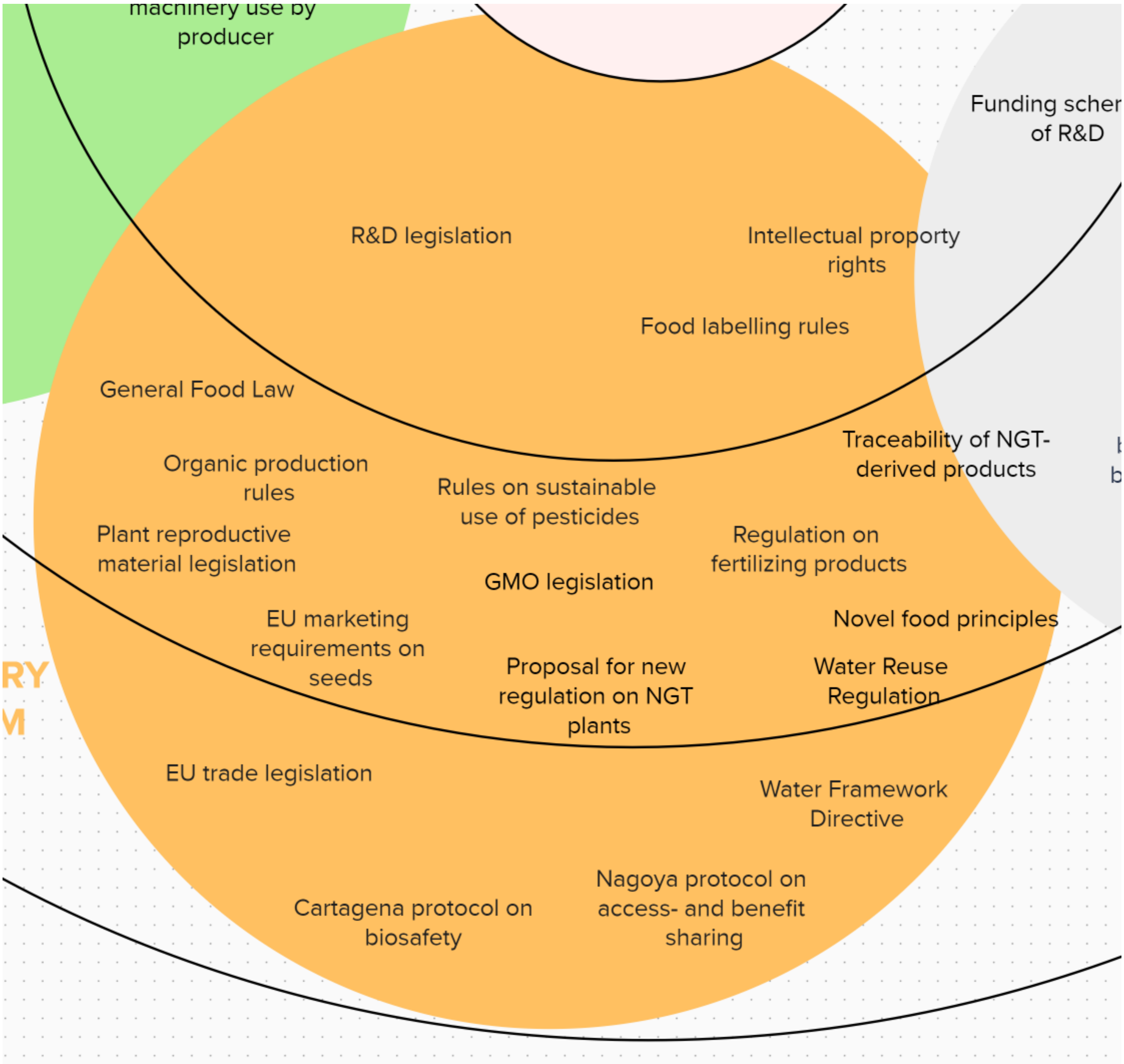

Figure 7: Regulatory subsystem of general systems map

The regulatory subsystem covers the laws, policies, directives and others that directly or indirectly relate to the production and marketing of starch potatoes. As this systems map reflects the 'As-is' situation of the starch potato production, most of the elements do not directly relate to the NGT-topic. Nevertheless, several elements still relate to the NGT debate since the map is framed from the potential impacts of new genomic techniques.

In the workshops, 18 elements were identified. Three of these are located at the Business/Individual level. The first, the **rules on food labelling,** directly refer to the responsibility of the individual sellers of food or beverages to provide accurate, understandable, correct and indelible information to the consumer (European Union, 2024). Second, **Intellectual property rights** directly affect individual businesses, particularly R&D actors and seed companies, regarding control over proprietary genetic material and innovations. While influenced by broader regulations, they are enacted and defended at the business level. This element is visually close to the political subsystem because the patenting of NGT seeds is an important point of discussion withing the gene editing debate. Third, **R&D legislation** applies directly to individual businesses engaged in research and sets the legal framework within which they operate at the business level.

Most of the elements in the regulatory subsystem are part of the food system level. **The general food law** governs food safety throughout the entire food system, influencing all actors involved in food production, processing, and distribution. **Rules on organic production** shape the standards for what qualifies as organic. It refers to every stage of the production process, from seeds to the final processed food (European Commission, n.d.-c). The **plant reproductive legislation** affects the breeding, certification, and sale of plant material across the agricultural system (European Union, 2023). While influencing individual actors, it is set at the food system level. The same is true for the **Water Reuse Regulation**. These rules aim to advance the reusage of water in the EU by setting out guidelines for a series of responsible parties, including farmers, across the system (European Union, 2022).

Another element in the Business/Individual level of the Regulatory subsystem is the **EU marketing requirements on seeds.** These apply across the seed industry within the EU, impacting all stakeholders involved in seed marketing and sales. Individual entities must comply, but the rules are part of the broader food system. **The rules on the sustainable use of pesticides** aim to reduce the risks and impacts of pesticides use on the environment and human health. The main actions relate to the whole food system, as it entails the training of users, advisors and distributors of pesticides, inspection of pesticide application equipment, the prohibition of aerial spraying, information and awareness raising (European Commission, 2012). Similar to pesticide regulations, **rules on fertilizing products** establish production standards at the food system level. The rules apply to the design, manufacture and placing on the market of EU fertilizing products (European Union, 2019).

In the middle of the regulatory subsystem are two elements that are crucial in the gene editing topic: the **GMO legislation** and the **proposal for new regulation on NGT plants**. The GMO legislation includes the multiple directives, regulations and supplementing rules that establish a legal framework of the development of modern biotechnology in the food system, specifically GMOs (European Commission, n.d.-a). Currently, NGTs are regulated under the same rules as GMOs, but a new proposal seeks to distinguish between the two through updated regulations for plants produced using certain new genomic techniques. If approved, this proposal would very likely accelerate research and development on NGTs.

However, if R&D on New Genomic Techniques would advance, it will need to align with the principles underpinning **Novel Food** accessing the food system in the EU. These include the safety for consumers, a 'proper' labelling, and novel food must at least be nutritionally equal compared to the original food (European Commission, n.d.-b). The final element in the level of the food system is the **traceability of NGT-derived products.** Just as the element *intellectual property rights,* traceability is bordering the political subsystem. Traceability of any food and feed produced for consumption throughout the food system is part of the General Food Law and is meant as a precautionary measure to respond to potential risks. Within the gene editing debate, traceability of NGTs is another important point of discussion as it would be needed to secure the freedom of choice for farmers and protect organic agriculture (IFOAM Organics Europe, 2024).

Finally, four elements are located in the level of the landscape. These relate to international agreements which are broader than the food system. The **EU Trade legislation,** for example, operates on a transnational scale, shaping market access and trade across borders. Related to international trade are the **Cartagena protocol on biosafety** and **the Nagoya protocol on access- and benefit sharing**. The former addresses the safe handling and transfer of Living

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Modified Organisms (LMOs) on a global scale, aiming to protect biodiversity and minimize the potential risks on human health (Secretariat of the Convention on Biological Diversity, 2000). Therefore, it impacts the regulatory context in which countries operate. The latter protocol impacts the sharing of genetic resources at a global level, affecting countries' policies (Secretariat of the Convention on Biological Diversity, 2011). The final element in the regulatory subsystem is the **Water Framework Directive**. This operates at a broad environmental management level. The Directive ensures an integrated approach to water management that goes broader than the national borders or sectors (European Commission, 2024b).

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Ecological subsystem

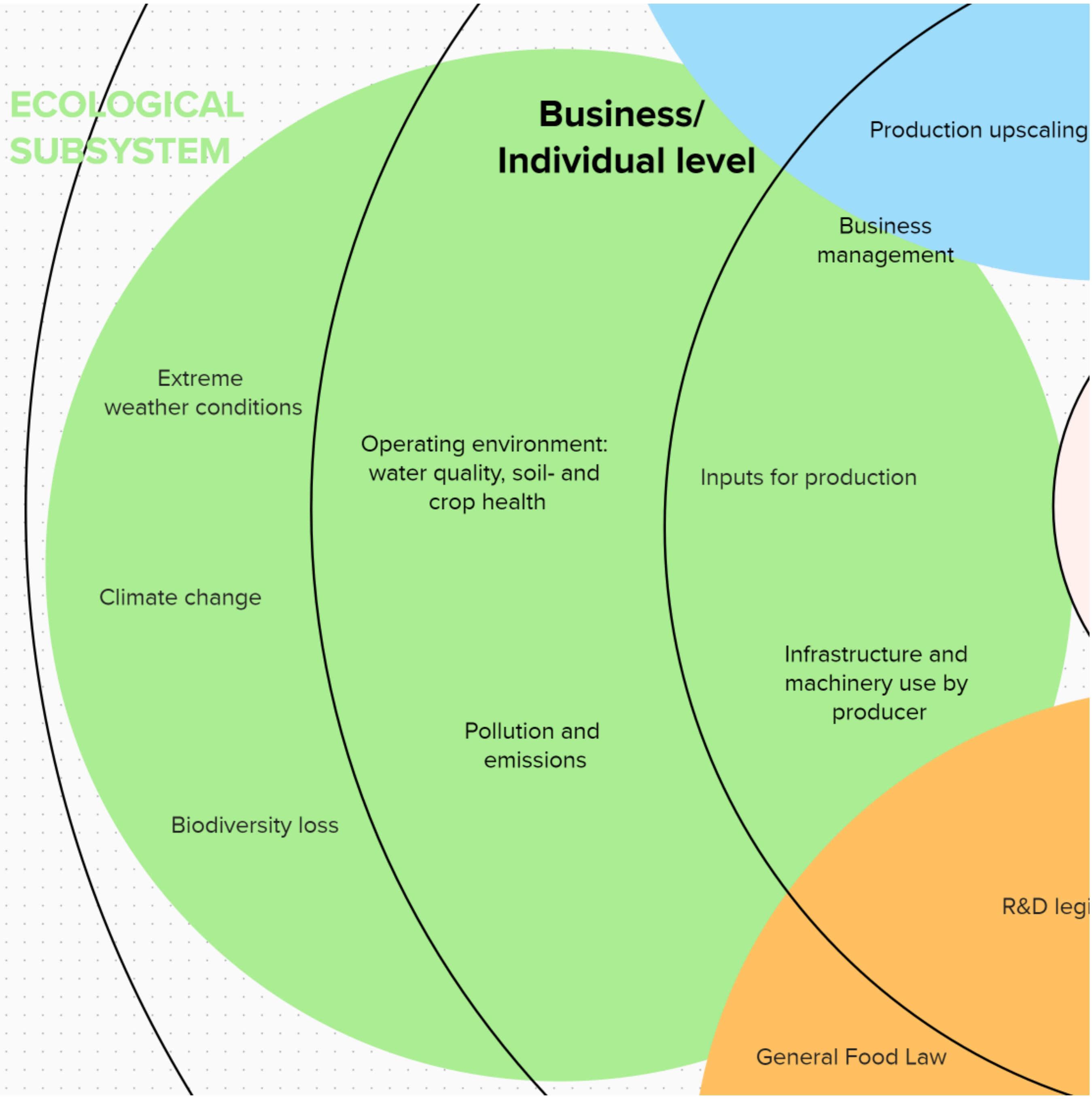

Figure 8: Ecological subsystem of the general systems map

In the ecological subsystem, elements at the Business/Individual level include business management, production inputs, and the use of infrastructure and machinery by producers. **Business management** refers to the strategies and practices employed by actors in the starch potato production system, such as farmers and value chain participants. While these management decisions are heavily influenced by elements at the Food System and Landscape levels, they ultimately remain individual choices, aligning with the Business/Individual level.

The business management and strategic choices made by actors determine the **Inputs for production** and the **Infrastructure and machinery use by producers**. The first relates to the essential inputs such as water, fertilizers and chemicals that are needed for the production and processing of starch potatoes. The second relates to the required infrastructure and machinery by farmers, business, retailers and other actors for producing, storing and processing the potatoes. Again, the use of these are based on individual strategic choices in the business management.

Moving to the wider food system, the **operating environment**—including water quality, soil health, and crop health—serves as a bridge between actions by actors working on the production of starch potatoes and landscape-level outcomes. For instance, widely adopted sustainable practices at the business/individual level can decrease the **pollution and emissions and improve the operating environment**, positively affecting the overall environmental conditions on the level of the landscape.

The **Landscape level** contains large-scale forces such as **(extreme) weather conditions**, **climate change**, and **biodiversity loss**, which exert top-down pressures on both the food system and individual practices. The three elements are of a global scale and have been influential for decades. Furthermore, individual businesses and even regional food systems have little influence on the three.

7. Possible impact of NGTs on the European starch potato production

As mentioned before, we are covering three key actors in the debate: ‘Conventional farmers’, ‘R&D actors’ and ‘Citizens’, and visualize and discuss the impact that NGTs would have on these groups. In the final report in 2025, we will expand our analysis by discussing other key stakeholders in the debate.

> **How to read the influence diagrams**
>
> In the visuals, the key elements for each actor are emphasized with circles and brighter colors. Continuous arrows represent a direct impact (negative, positive, or neutral) from the originating element to the target element. The influence diagram for citizens also includes dotted lines, which indicate the absence of an effect. These were specifically highlighted to underscore arguments suggesting that NGTs may not effectively address certain challenges.

Certain words in the explanation of the influence diagrams are formatted in **bold** to indicate their correspondence to the highlighted elements in the visualized influence diagram.

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The impact of NGTs focusing on conventional farmers

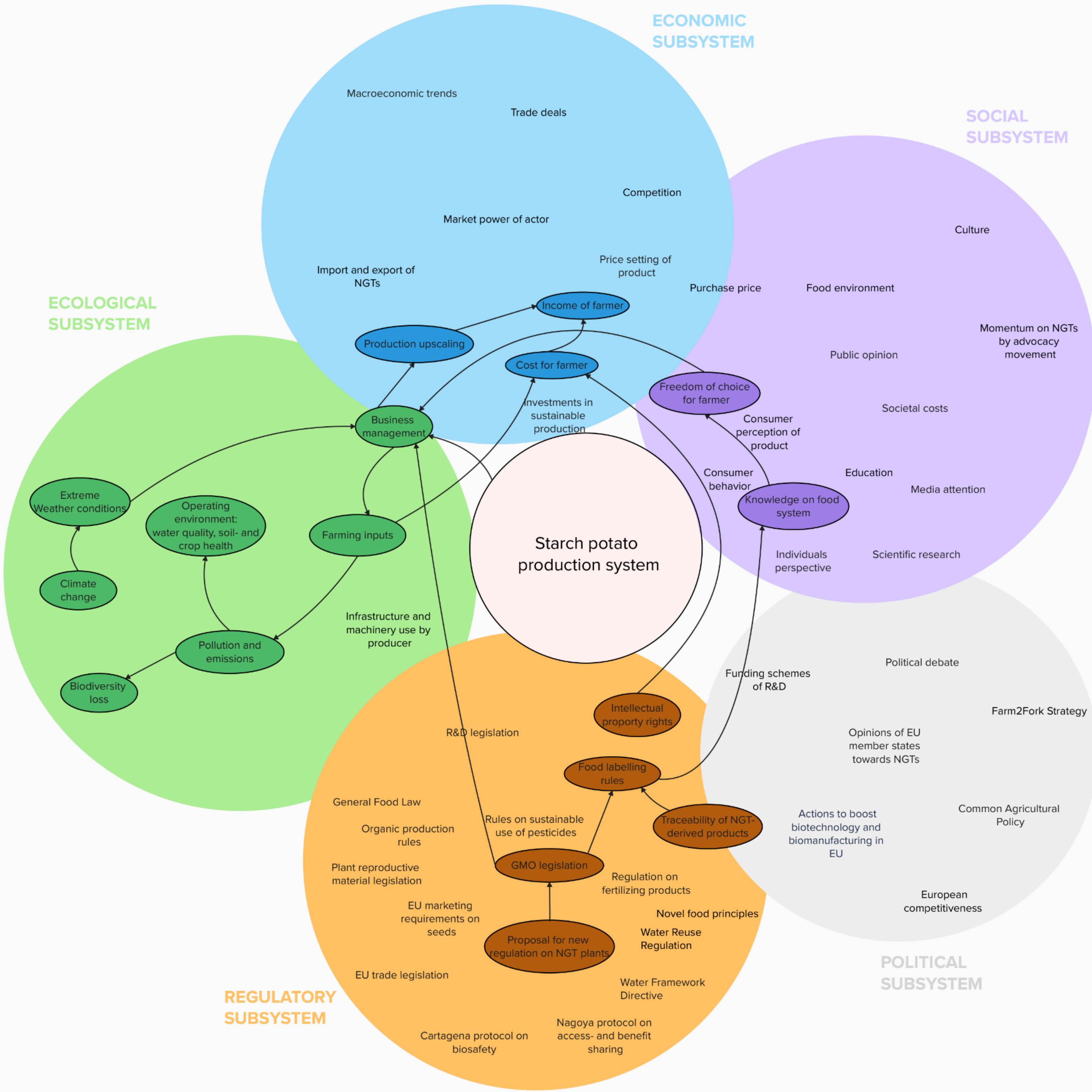

Figure 9: Influence diagram for conventional farmers

The introduction of New Genomic Techniques (NGTs) in agriculture could offer significant benefits for the **business management** of conventional farmers. As **climate change** is increasing the chances for **extreme weather conditions** and crop diseases, crops could be gene edited to be more tolerant to these events (Newbery et al., 2016; Selfa et al., 2021;

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Seneviratne et al., 2023). Furthermore, drought- or disease resistant crops would result in better yields, reduce the farmer's reliance on **inputs** such as pesticides and water (Głowacka et al., 2018; Phipps & Park, 2002), therefore reducing **pollution and emissions** and improving **biodiversity** and the condition of the **operating environment** such as the soil and nearby bodies of water. This increased resilience could also help safeguard food production in the face of global climate challenges. Moreover, a reduced need for inputs would save **costs** for farmers and better yields result in an **upscaling of the production** and a growing **income**. Additionally, improved valuable compounds – like GeneBEcon's work on a better starch quality (Eriksson, 2024) – would also benefit farmers' income.

An important counter-argument, however, is that some scientific publications indicate that gene editing does not lead to a reduction in pesticide use (Benbrook, 2012). Even more significantly, the reverse could be true. Benbrook (2012) shows that overall, genetically-engineered crops have led to an increase of pesticide use by 7% in the United States. Other studies find mixed results, depending on the kind of trait and crop (Coupe & Capel, 2016).

It is uncertain how the introduction of NGTs would affect the seed prices for farmers (which is part of the **cost for farmers**). Monopolization and a lack of competition could inflate the prices, even leading to "predatory pricing" wherein GM producers first eliminate non-GM crops from the market by setting artificially low prices, after which they raise prices again (Munro, 2003). However, proponents of NGTs often claim the opposite; the efficiency and cost-effectiveness of CRIRSP-based techniques will lead to a democratization of the access to the crops (Xia et al., 2021). In sum, it is very important to be thoughtful about the **intellectual property rights** and NGT patenting to guarantee fair **prices for farmers**.

Importantly, if category 1 NGTs would be excluded from the **GMO directive** following the **new proposal** – and therefore adding the possibility of producing NGT-crops in the management of the farmer – it is crucial to recognize the need to uphold the **freedom of the farmer** to be able to choose whether or not to use NGT-derived seeds in their **farm management**. Ensuring transparency through **labelling** and **traceability** of NGT-derived products is the key for allowing farmers to make informed decisions ('**knowledge on food system**'), to ensure their freedom to choose about their participation in NGT-based agriculture.

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The impact of NGTs focusing on the R&D actors

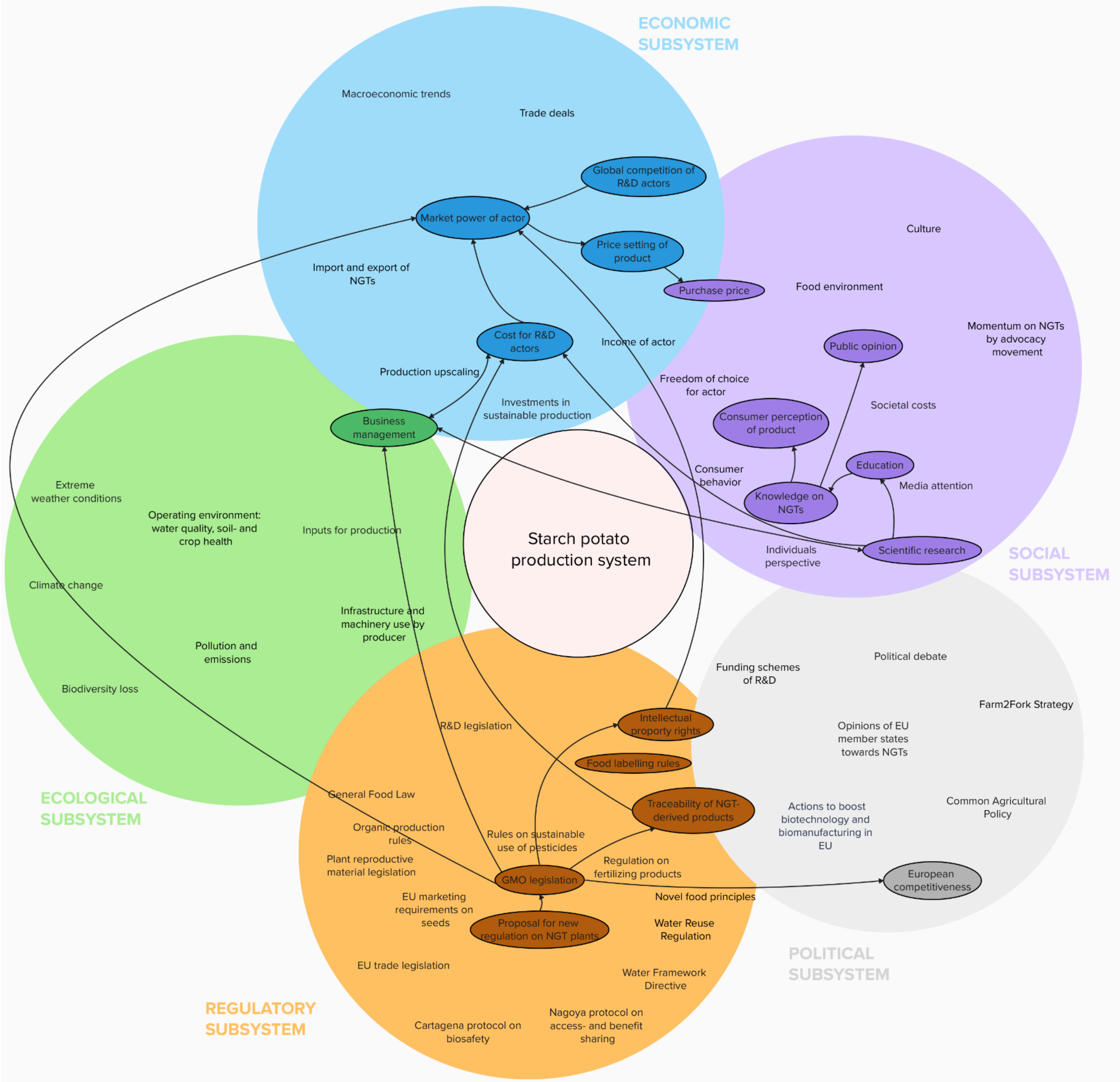

Figure 10: Influence diagram for R&D actors

Actors from the research and development (R&D) sector argue that the introduction of New Genomic Techniques presents numerous advantages. NGTs are faster, more precise, and produce results that are "natural-like," as they allow scientists to perform highly targeted modifications without the need to introduce foreign DNA (Belderok, 2021; Xia et al., 2021). This precision makes NGTs more accurate than traditional breeding methods or random mutagenesis, enabling quicker **scientific research** at a lower **cost for the R&D actors**. This increased speed allows R&D to provide faster innovative solutions to the agricultural and processing industries, which influences their **business management**. Moreover, the end products of NGTs can resemble natural selection or mutation (Belderok, 2021; Strobbe et al., 2023). Therefore, several workshop participants stated that the **public opinion** and the **consumer perception** of NGTs should improve if **scientists** would be trying to **educate** the public, increasing the common **knowledge** on NGTs.

Additionally, if **GMO legislation** was made more flexible by adopting the **new NGT proposal**, the amount of R&D activities would further increase. Less stringent regulations could enable R&D actors to incorporate more **research** activities within their own **management**, allowing for faster and more cost-efficient development. Currently, the GMO directive imposes significant **costs** for R&D actors due to the need for special measures (f.e. complex approval processes), which hinders **research output**. Strict rules on **traceability** for making **labelling** possible also impose additional **costs** on R&D actors, further influencing the **management** of these organizations.

The adoption of NGTs also opens doors to otherwise missed opportunities for the European R&D sector compared to the **global R&D competition**. It was argued that practically banning these techniques does not stop innovation in other countries and may risk a EU brain drain, where researchers and companies relocate to regions with more flexible regulations. By maintaining the stringent GMO legislation, proponents argue that the EU is losing both global **competitiveness**, **market power** and innovative capacity. In contrast, supporting NGT research could keep Europe competitive on the global stage.

The democratization of genetic techniques could be another benefit for the R&D community. Some NGT technologies are increasingly becoming **affordable** and accessible for smaller companies. There are also platforms offering certain gene-editing technologies for free, provided they are used for research purposes, further expanding opportunities for smaller R&D actors to participate in cutting-edge innovations. The update of GMO legislation could therefore have positive effects on the **market power** of small R&D actors.

On the other hand, however, critical voices share their concern about the monopolization of NGTs by large corporations. As long as NGT inventions can be patented through **Intellectual Property rights**, big enterprises could start to dominate the NGT R&D market and limit access for smaller companies. Patent holders could secure exclusive rights, thereby restricting others from exploiting new genetic traits and consolidating **market power**. Furthermore, the monopolization could lead to **price inflation**, as corporations would control the **price setting** (Munro, 2003).

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The impact of NGTs focusing on citizens

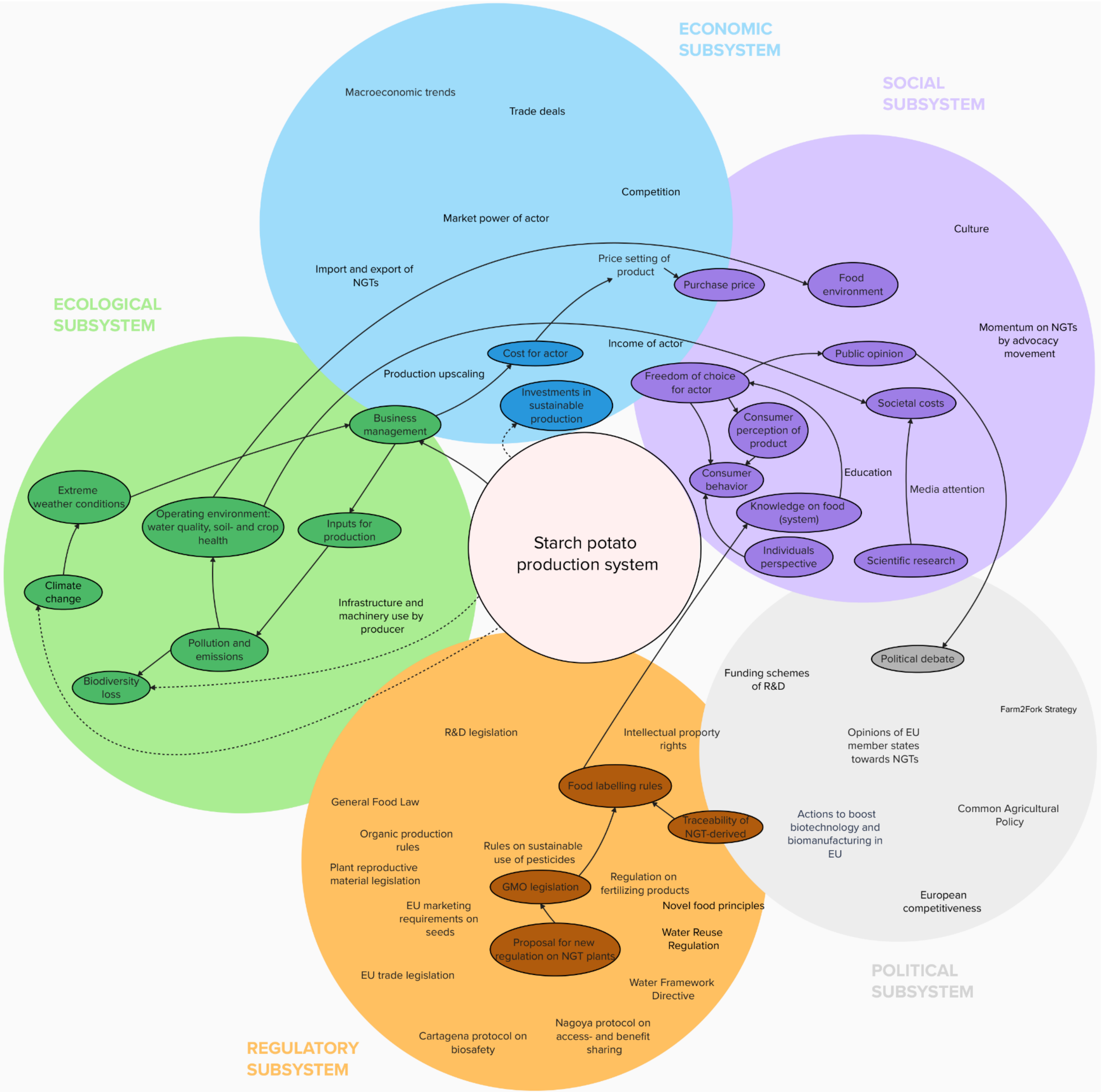

Figure 11: Influence diagram for citizens

From a citizen's perspective, the introduction of New Genomic Techniques (NGTs) into agriculture presents both opportunities and concerns. On one hand, NGTs can contribute to a more sustainable bioeconomy by reducing businesses' dependence (i.e. their **business management**) on **inputs like chemicals, pesticides and water** (European Commission, 2023b). This will result in less **pollutions and emissions** and an improved **biodiversity** and **operating environment,** such as a better water- and soil quality. This aligns with the public demand for environmentally friendly farming practices. NGTs also hold the potential to help adapt to **climate change** and address food insecurity by developing crops that are more resilient to **extreme weather conditions** (Selfa et al., 2021; Seneviratne et al., 2023). Ultimately, this results in reduced crop losses for farmers and businesses, which lowers production costs. These cost savings can potentially translate into more affordable **purchase prices** for consumers.

Additionally, a reduced need for pesticides in NGT-derived crops could lead to a healthier **environment** and food, therefore reducing **societal costs** (such as potential health implications) and creating a better **food environment** as more healthy food would be available for citizens. With proper labelling and traceability in place, citizens would have more options when making informed food choices (this relates to the element **'knowledge on food'**), which proponents view as a positive development.

While these benefits are promising, there are significant concerns regarding the scientific certainty about new genomic techniques. First, there are big differences between promising 'lab' findings and actual improvements in practice (Fischer & Rock, 2023). For example, as we already mentioned above, studies find mixed results regarding pesticides reduction by GM crops in practice, some even showing an overall increase of pesticide use (Benbrook, 2012; Coupe & Capel, 2016). Second, the introduction of NGTs could open a Pandora's Box, as there is limited **scientific research** on (long-term) **societal costs** such as potential long-term environmental and health impacts. For scientists, it is challenging to completely guarantee the absence of unintended consequences. This concern is particularly valid given that there are documented cases of, for example, gene edited[6] Canola 'escaping' into the wild in the USA (Travers et al., 2024). It is argued that the precautionary principle should therefore guide the development of NGTs, focusing on minimizing risks before widespread adoption. Thus, a **new NGT regulation proposal** should maintain a strict **GMO Directive** that guarantees safety.

Moreover, an important argument is that NGTs do not address the root causes of global challenges like **climate change, biodiversity loss**, pests, and food insecurity[7] (Robinson et al., 2022; Van Dyck & Kenis, 2023). These issues are primarily driven by social and economic factors that require systemic solutions, rather than technological 'quick-fixes'. Focusing on NGTs would therefore be a distraction from making effective **investments in sustainable production**. Furthermore, NGTs could reinforce existing problems in the food system, such as the agrochemical industry's control of food production, monoculture practices leading to the loss of genetic resources and overall pesticide use (Benbrook, 2012; Fischer & Rock, 2023; Gonzalez, 2011). It was therefore suggested that shifting farming practices toward more holistic, sustainable approaches would be a better solution than relying on NGTs.

Finally, the principle of **freedom of choice** is crucial for many citizens. It was argued that all actors in the value chain must have the ability to choose whether or not purchase NGT-based products. Furthermore, studies show that lowering the consumers freedom of choice generally leads to a negative **perception** and that the public is a strong supporter of mandatory labelling of gene edited products (Argouslidis et al., 2018; Wunderlich & Gatto, 2015). This underscores the importance of a **GMO legislation** that ensures transparent **labelling** and **traceability of NGT products.** If not done with care, a huge backlash in the **public opinion** could be created, which will heavily impact the **political debate**. To mitigate this risk, individuals should be able

[6] It is important to note that the editing technique of the Canola were not new genomic techniques.
[7] This is indicated on the influence diagram by dotted lines.

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to make informed decisions about what they buy based on their own **perspective**, **perception**, and values.

8. Conclusion

This report represents the second phase of the systems mapping approach within GeneBEcon. By organizing three workshops with relevant stakeholders, we aim to visualize the complex interconnections between social, regulatory, political, economic, and environmental factors while exploring the potential risks and benefits of new genomic techniques (NGTs) for the European bioeconomy. The third and final report in this approach is scheduled for publication in the summer of 2025, coinciding with the conclusion of GeneBEcon.

In this report, we are focusing on the production and processing systems of NGT starch potatoes within the European bioeconomy. These are visualized through a ‘general systems map,’ which highlights elements critical to the production system of starch potatoes. The map is framed by the European debate on the potential impact of NGTs and categorizes elements into specific system levels, based on whether they relate to individuals or businesses, the broader food system, or the overarching ‘landscape.’ Each element is further classified into one of five subsystems: social, regulatory, political, economic, or ecological. In sum, it is important to consider a wide range of factors when assessing the potential impact of new genomic techniques on the European bioeconomy. These factors relate to numerous domains.

The effects of NGTs on the European bioeconomy **depend heavily on one’s role and position within the system**. To reflect this complexity, we have visualized the potential impacts (risks, benefits, or neutral effects) through actor-specific ‘**influence diagrams**.’ While eight relevant actors were initially identified (conventional farmers, R&D actors, citizens, organic farmers, civil society organizations, scientists, value chain actors, and EU member states), this report focuses on the first three. These actors emerged as the most prominent during the workshops and represent distinct and non-overlapping perspectives regarding the effects of NGTs.

For **conventional farmers**, the introduction of new genomic techniques could be beneficial by offering tools to address the challenges posed by climate change, such as extreme weather events and crop diseases. NGT crops resistant to droughts and diseases would improve yields and reduce the reliance on inputs like pesticides and water, leading to cost savings and reduced pollution. However, concerns remain regarding the effective impact of NGTs in practice. Some studies demonstrate mixed effects regarding reduction of pesticide-use. Moreover, there are uncertain effects of NGTs on seed pricing, particularly in the context of market monopolization risks. Moving forward, it is essential to ensure transparency through labelling and traceability, allowing farmers to make informed decisions and safeguarding their freedom of choice.

For **R&D actors**, NGTs offer significant advantages by enabling faster, more precise, and cost-effective research. This will support innovation in farming and processing industries while improving the global competitiveness of European R&D. Less stringent regulations could further accelerate research and field trials, reducing costs and fostering opportunities for smaller R&D actors through democratized access to genetic techniques. However, here too remain concerns about potential monopolization by large corporations. These could restrict access for smaller companies and inflate costs without the essential regulation regarding patenting.

For **citizens**, the potential impacts are concentrated on the ecological and social subsystems. On the one hand, NGTs can support a more sustainable bioeconomy by reducing pollution, and offering healthier food options with fewer societal costs. This could help address food insecurity while lowering costs for consumers. However, concerns persist about the uncertainty

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of long-term societal and environmental impacts. Additionally, NGTs may not address the root causes of agricultural challenges like climate change and biodiversity loss, potentially diverting our attention from more sustainable and systemic solutions. Transparency and freedom of choice remain pivotal for public acceptance, emphasizing the necessity of labelling and traceability to avoid backlash and ensure informed decision-making.

Next steps

Following two workshops, several critical questions remain unanswered. First, this report has concentrated on the impacts of NGTs on only three stakeholder groups. It is likely that other stakeholder groups will exhibit similar influence diagrams. For instance, the impacts of NGTs on citizens may closely resemble those identified for civil society organizations. Expanding the analysis to include additional relevant stakeholders in the European bioeconomy and identifying parallels between stakeholder groups will be essential to strengthen the comprehensiveness of the systems mapping approach.

Second, to enhance the utility of the systems mapping framework, we aim to identify ‘intervention points,’ or key leverage points where policymakers can direct their efforts to foster holistic and systemic change. These intervention points represent elements critical to the narratives of all stakeholders. For example, the regulation of intellectual property rights and the labeling of NGT-derived products have emerged as pivotal issues in this context. Identifying and exploring such intervention points during the final workshop will be crucial for developing sustainable, inclusive solutions.

Third, while this report has mapped the general starch potato system and the potential impacts of NGTs, the influence diagrams remain relatively superficial, primarily addressing the visible impacts of NGTs. Following the Iceberg Model theory (Guynn et al., 2022), deeper layers, like the underlying structures and mental models that drive these events, have not been fully explored. For example, this report highlights conflicting perspectives: some argue that deregulation of NGTs will democratize access to these technologies, while others contend it will lead to market monopolization. These contradictions stem from differing values and belief systems among participants. Delving into these foundational layers would add significant depth and nuance to the debate, offering a richer understanding of the dynamics at play.

These questions will be addressed in the final phase of the systems mapping approach, with the next workshop scheduled for **24 February 2025**. We hope to see you then!

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We welcome your questions, comments and suggestions.

9. Literature

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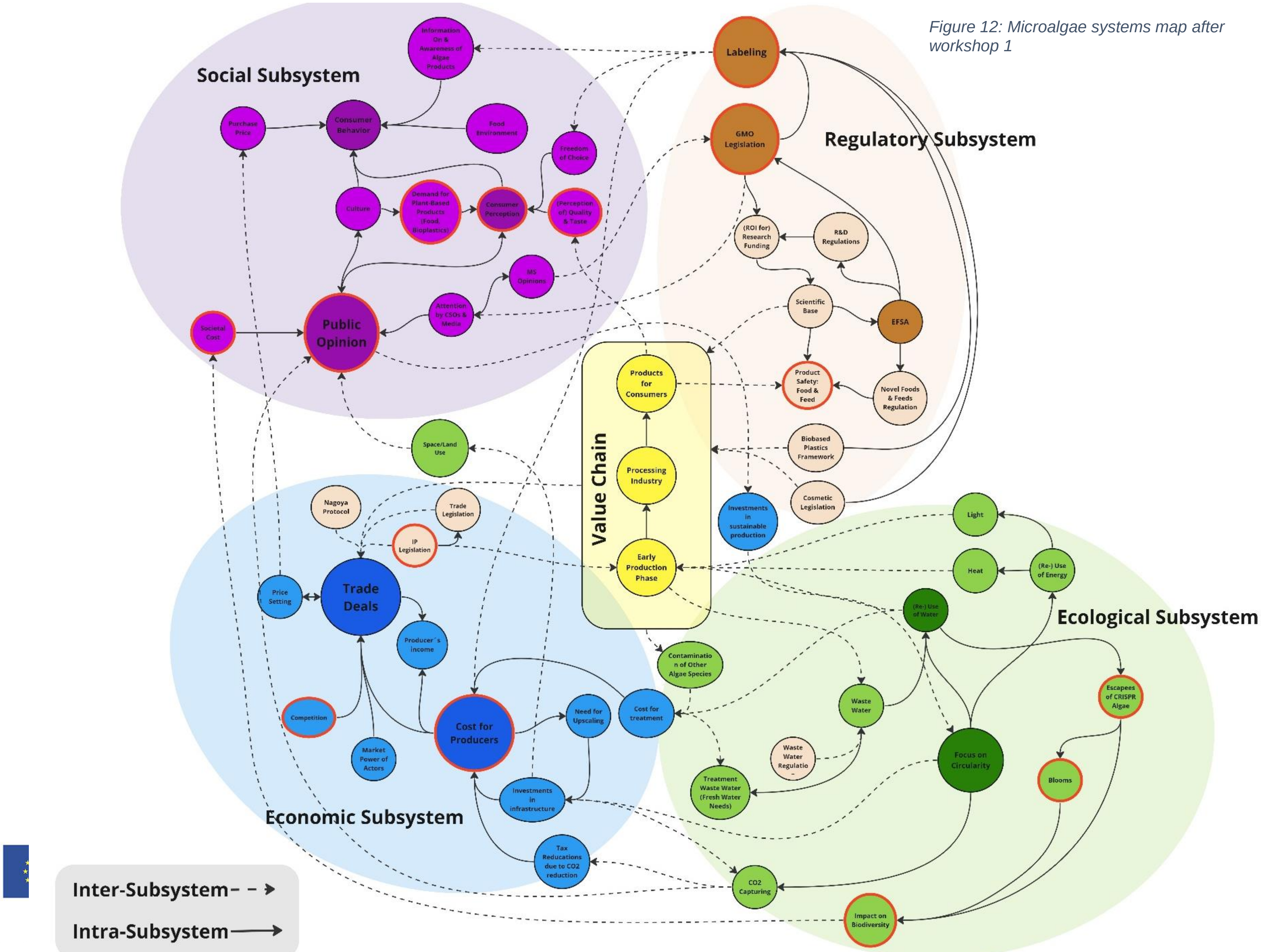
Figure 12: Microalgae systems map after workshop 1



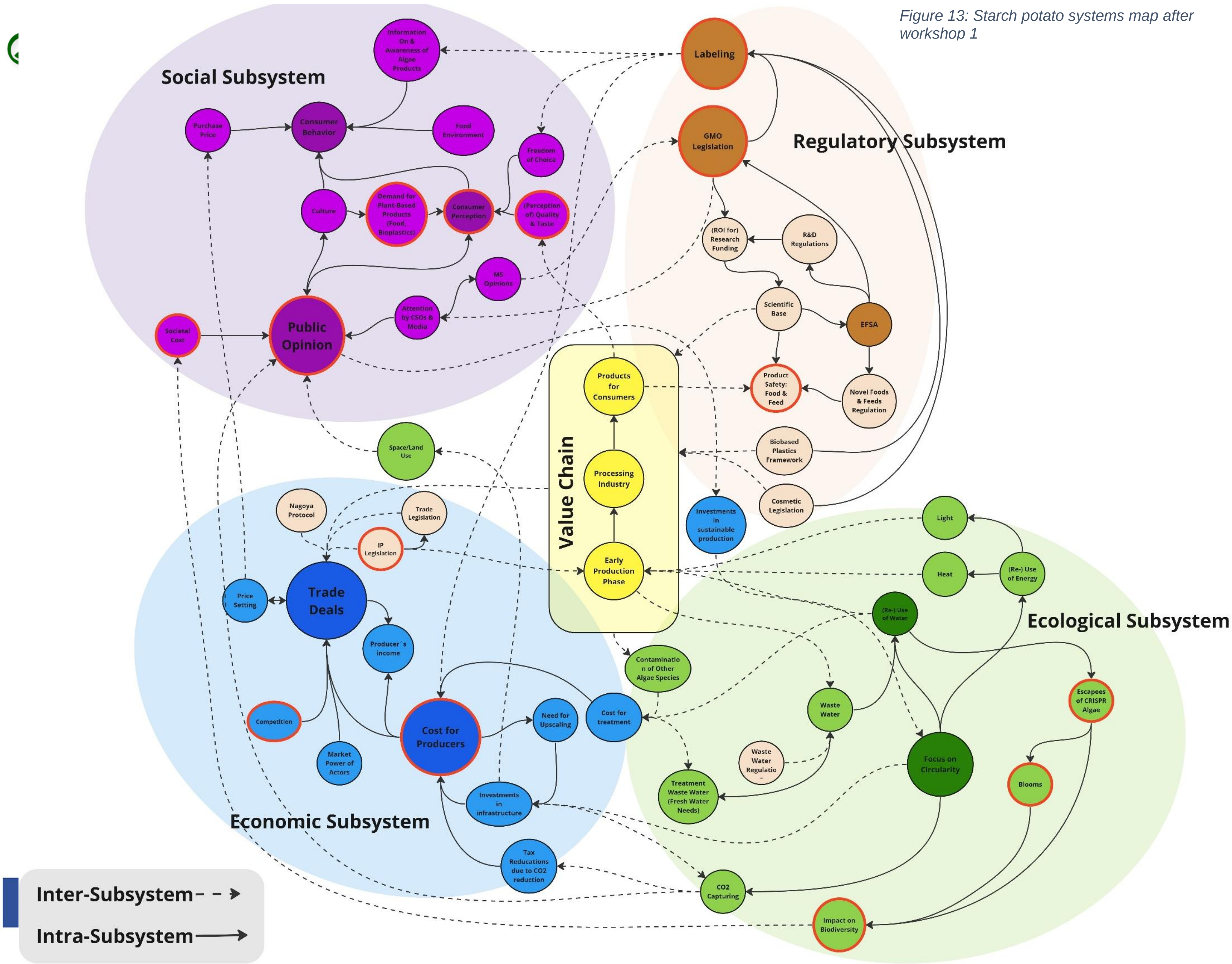


Figure 13: Starch potato systems map after workshop 1

Addendum

A. Microalgae systems map

The microalgae systems map that was developed after the first workshop consisted of environmental, economic, social, and regulatory subsystems. This was an "as-is 2023" systems map, which means that no NGT-derived microalgae products are available on the European market. The key message of this map is the interconnected of the elements in and between subsystems. Furthermore, a status-quo of the NGT regulation is the most risk-averse option, but could lead to missed (economic) chances. Deregulating NGT-microalgae in the GMO directive brings considerable potential risks, relating to public opinion, monopolization and losing the freedom to choose if there is little traceability. Simultaneously, it could lead to an improved production of valuable microalgae compounds, resulting in healthier food and other microalgae products.

Other takeaways, relating to each "as-is" subsystem include:

Ecological subsystem: Microalgae require water, light, and heat to grow, with optimal conditions enhancing biomass yield and valuable compound production. Sustainable practices include using wastewater for nutrient supply and pollution mitigation, recycling water, and leveraging microalgae biomass as a renewable energy source. Microalgae also capture CO2 and release oxygen, contributing to carbon emission reductions. However, large-scale cultivation may compete with agricultural land.

Economic subsystem: Production costs are influenced by the choice of cultivation systems (open ponds vs. photo-bioreactors). While photo-bioreactors (PBRs) offer higher yields and better contamination control, they incur significant capital and operational costs. Cost efficiencies can be achieved through process upscaling, circular resource use, carbon credits, and advanced infrastructure.

Social subsystem: Microalgae products are versatile, spanning food, cosmetics, pharmaceuticals, bioplastics, and energy. Positive public opinion is driven by health and sustainability benefits, but public perception is sensitive to land use and resource consumption impacts. Consumer education and transparent communication about product benefits are vital for acceptance and market growth.

Regulatory subsystem: Unique to microalgae are the absence of seed legislation and the addition of cosmetic and bioplastic regulations, focusing on safety, sustainability, and product labeling. Effective regulatory alignment supports the sector's growth and public trust.