Mapping the system: Systems thinking in the European Gene Editing debate

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1. Introduction

Dear reader,

You are participating in the 2nd Systems Mapping (SMA) workshop of GeneBEcon, organized on April 17th, 2024. Many thanks for that. This document serves as a preparation with practical details and background information about systems thinking, the doctoral research of Sil Allaert and the results of the first SMA workshop.

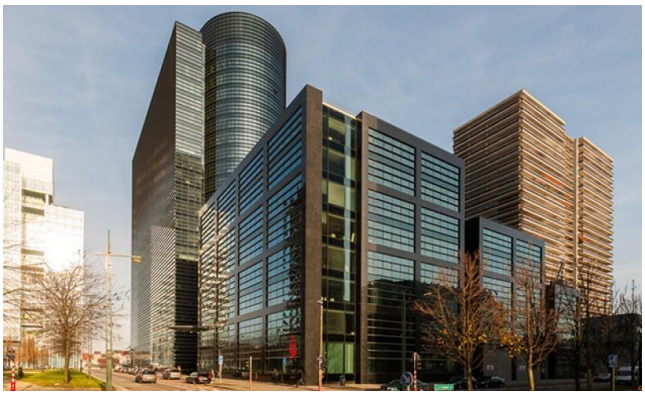
It is important to note that gene editing is a polarized topic with many different perspectives. During the workshop, we aspire to create a safe environment where everyone's input is equally valuable. Furthermore, the results of the first systems mapping workshop was based on the input of the participants, our own understanding of the topic and scientific literature. Our approach is still a work in progress and we look forward to learn about your perspective in the workshop.

Should you have any concerns/comments about the information in this document, please let us know (via mail or during the workshop).

Practical information

The first workshop is planned **live in Brussels** on **April 17th from 9AM to 1PM.**

It is held in the Ellipse building (Boulevard Roi Albert II 35, 1030 Brussels) in room 0.A.11. The building is on a 5-minute walk from the Brussel North train station. Drinks and a social lunch will also be provided that day.



GeneBEcon

GeneBEcon is a Horizon Europe-funded project that is examining the innovation potential of gene editing in enabling a sustainable bioeconomy in Europe. The potential of new genomic techniques (NGTs) is studied and applied in 2 production systems which act as case studies; **starch potato**, representing an agricultural crop production system, and **microalgae**, representing a contained production system with microorganisms. More specifically, the research in GeneBEcon will use gene editing to develop 1) a virus-resistant potato with an industrial tuber starch quality, and 2) microalgae-based production of industrially relevant mycosporin-like amino acids. GeneBEcon's results aim to support the European Green Deal, The Circular Economy Action Plan, And The Bioeconomy Strategy. The project's results are disemminated to scientists, policymakers, plant breeders, farmers, industry and consumers.

More information about the project can be found on the website and in the brochure.

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2. Systems thinking

Systems thinking, an approach to understand wicked problems, is crucial for the GeneBEcon project. Currently, the debate about genetically modified organisms (GMOs) and new genomic technique (NGTs) is often polarized, with little bridges between the multitude of different perspectives. In a series of three workshops (2023, 2024, 2025), we strive to understand the complex interrelationships between social, regulatory, economic, and environmental factors that influence the debate about and development of new genomic techniques. 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 **system map**. It helps to illustrate the relationships and interactions between various components or elements within a system and provides a holistic view of the system, highlighting connections, feedback loops, and dependencies to help understand its structure and dynamics.

The system maps presented below **are not final yet**. The included elements are not exhaustive. Furthermore, a system map – even after many workshops – can improve with a stepwise approach but will never be completely accurate because it depends greatly on the diversity of the group of participants, diversity in knowledge, on perspectives on the issue and on the context in time (current regulations, debate in the media, etc.). It is thus important to strive towards participation from a range of actors with knowledge and opinions on the matter. In particular, our main aim is to understand and learn on the issue at hand, to get insights on connections and loops within the system, and to build bridges between different perspectives. The second and third workshop will be used to progress the system approach, to gather even more perspectives and to look into the potential impact of NGTs in the latest regulatory context.

3. Doctoral research of Sil Allaert

There has been a growing recognition of systems thinking as valuable addition to study wicked problems in food- and farming research projects. Typically, a Systems Analysis is constructed by engaging with a diverse group of stakeholders to involve and consult their expertise. However, these stakeholders often have conflicting opinions in polarized debates. Assembling a diverse group and setting up constructive dialogue is not evident. Different strategies to overcome polarization exist, but it is unclear how these are best applied to multi-stakeholder systems research.

In his PhD, Sil will therefore investigate different systems thinking methodologies in multi-actor projects about polarized topics in food and agriculture. He will explore how systems methodologies influence collaboration with and between stakeholders, and how those methodologies can help bridge polarization. By increasing our knowledge of this topic, systems thinking will further improve as method to study polarized debates, while simultaneously bridging polarization by bringing different stakeholders together in a constructive setting.

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4. Key learnings after the first SMA workshop

Key messages about systems thinking:

- Systems thinking can support our holistic understanding of the various intended and unintended consequences, risks and benefits of introducing NGT-derived products in the bioeconomy.
- By using systems thinking, the different actors in the debate have the opportunity to see 'the bigger picture' and to connect with people with other perspectives. Thus, it could help in tackling the polarization in the debate.

Key messages about the approach of the researchers:

- Our findings presented in this report are a first step and based on a workshop, organized in March 2023.
- The results are based on a snapshot, influenced by the participants and the time in which the workshop was organized. Yet, we still believe we can make several statements due to the fact that various elements recurred numerous times during the workshop.
- Two more workshops and a literature review will be organized to further improve the system maps and the validity of the approach.

Key messages about the results:

- There are many elements that are important to think about when introducing NGT-derived organisms in the European bioeconomy. These can be grouped in four clusters: 1) Economic, 2) Ecological, 3) Social, and 4) Regulatory.
- Everything is connected. Elements influence each other within groups, as well as between clusters. When one element changes, this will impact the whole system.

Possible risks & benefits NGTs:

In case that the regulation about certain new genomic techniques is made more liberal and the use of NGTs in the bioeconomy becomes mainstream, we expect various **possible benefits.**

- Costs of development would reduce. The speed of R&D and investments would both increase.
- The need for chemical inputs would be reduced. Yields and the amount of interesting compounds could improve.
- These changes could lead to healthier food and boost the development of natural products.
- Farmers, industry and consumers would have more varieties to choose from.
- Smaller companies could have more opportunities for seed R&D and marketizations.

On the other hand, **various risks** could also occur.

- Due to patenting and intellectual property, changes are that the market would close itself because of monopolization and consolidation by the big businesses.
- If no traceability systems exist, no retraction is possible when something unexpected would occur. Liability would become impossible.
- Without labelling, farmers, industry and consumers would not be able to choose according to their preferences.
- The public could become very negative towards gene edited products, which affects the consumer behavior.
- In a 'battle for attention', fake news and misinformation could become dominant.

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5. Results of the first system mapping workshop on March 1st, 2023

The first workshop was organized on March 1st, 2023. Using its results and backed with scientific literature, two systems maps were constructed. At the time of writing the report, the new NGT proposal (which distinguishes plants into two categories) **was not published yet**.

Conforming to the general focus of GeneBEcon, the maps were based on the production, processing and consumption of starch potato and microalgae products. The nodes represent key elements within the four subsystems that significantly influence the bioeconomy. The color of the nodes relates to the subsystem it belongs to. Green for ecological, blue for economic, purple for social and brown for regulatory. Both system maps thus consist of the value chain in the center and numerous nodes and arrows around it, clustered in subsystems. These nodes influence each other, which is indicated with arrows. The size of the nodes indicates a qualitative visualization of the 'importance' of the element. A node is bigger when it affects and is affected by multiple other factors, or if we believe that the node has a lot of influence on the system as a whole.

We already stated that GeneBEcon explores the technical potential of NGTs using two cases: starch potato and micro algae. In our systems thinking approach, we are using these cases as starting point to provide the system maps with a focus. Furthermore, in the workshop on April 17th, we will only be using the starch potato case as central point of discussion. This because the system maps of both cases are quite similar and also for efficiency reasons.

Below, the starch potato system map is presented and explained in detail. **We will also present this during the workshop**, but feel free to already inspect the whole map. We do encourage you to read at least one subsystem to have an idea about the SMA approach.. It is important to understand that the system maps below illustrate the situation as it is now, e.g. with the current GMO regulatory framework, but **without a systemic impact of NGTs**. In the workshop, we will discuss the potential systemic impact of NGTs.

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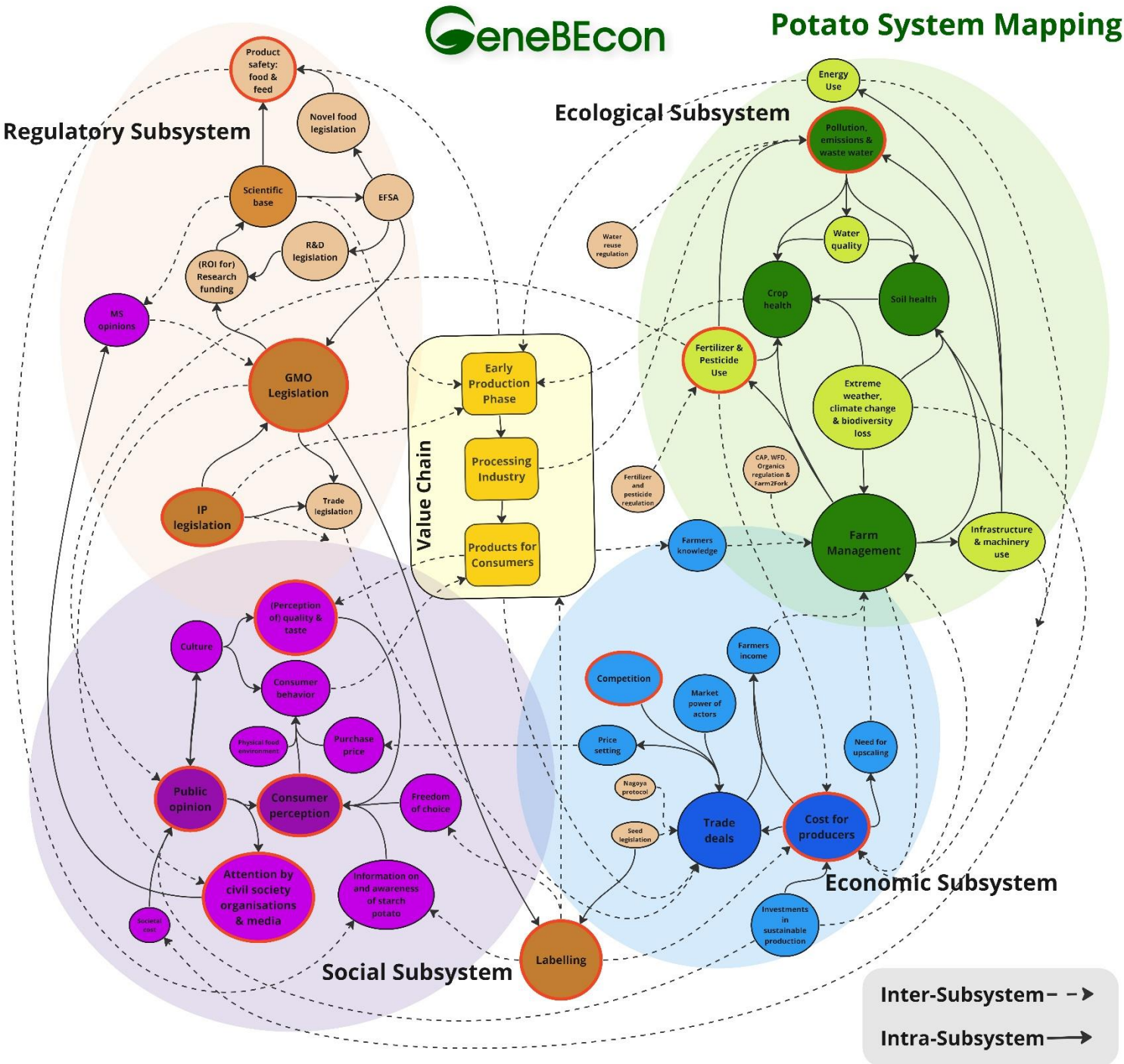

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Starch potato system map

A. Ecological subsystem

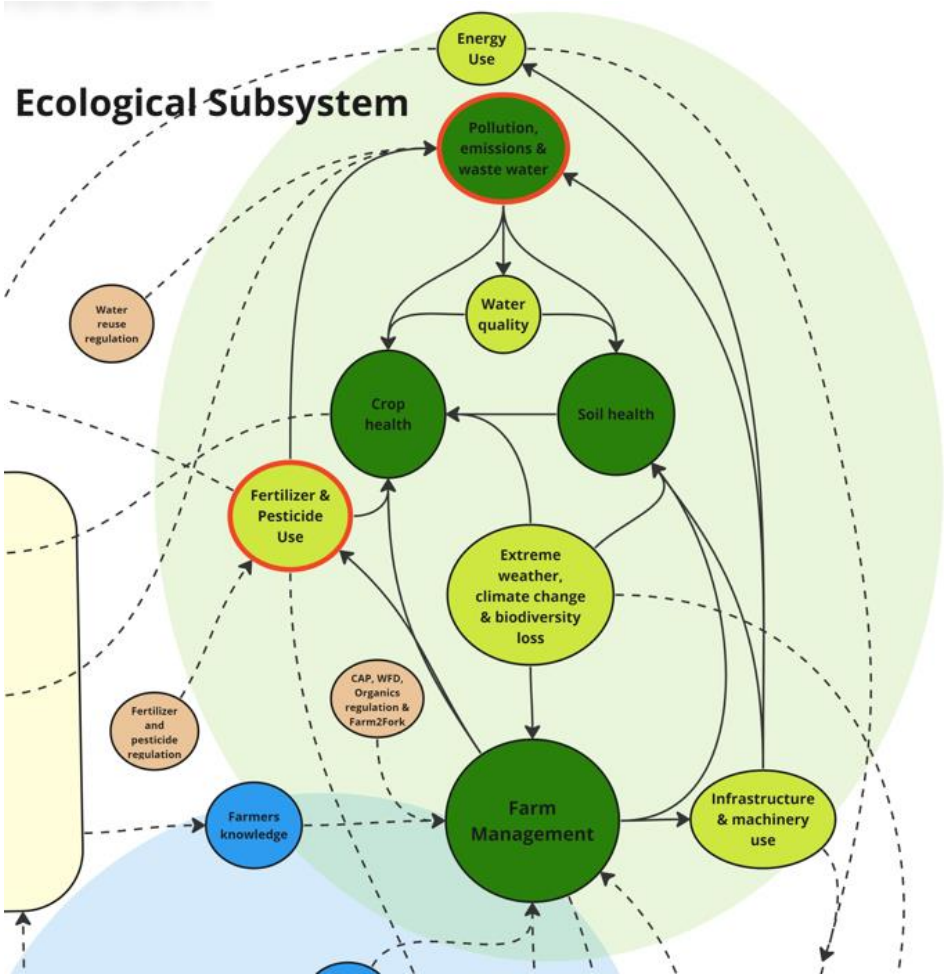

Figure 3: Starch potato - Ecological subsystem

The farmer's **land and farm management** is a crucial element when considering the ecological effects of the production of starch potatoes. In their management, today's farmers are obliged to take a variety of factors into account. They operate in a context where multiple regulatory frameworks and directive policies about agriculture apply, such as the **common agricultural policy (CAP)** (*CAP at a glance*, 2023), the **Farm to Fork Strategy** (*Farm to Fork Strategy,* z.d.), **fertilizer** ((*EUR-Lex - 4406079 - EN - EUR-Lex*, z.d.), **pesticides** (*Approval of active substances*, z.d.; *EU legislation on MRLs*, z.d.) and **waste** (*Waste Framework Directive*, z.d.) **regulations**. In addition, economic processes influence the farmers income and may increase the **need for the upscaling** of the farm (MacDonald et al., 2007), while broader societal trends and thus **the public opinion** are steering towards **investments in sustainable agriculture** (Spedding, 1998). The increasing societal ambition towards a sustainable agriculture is driven by the **biodiversity crisis, climate change** and its effects, such as **extreme weather phenomena** (*Farm to Fork Strategy,* z.d).

These crisis's also directly influence the health of the **soil** and the **crops** (Baumhardt, 2003). And furthermore, it is increasingly evident each year that farmers should adopt **a management system** that is adaptive to climate change. The **knowledge of the farmer** plays an important role in this adaptation. By understanding how ecological elements (pollution, drought, soil, etc.)

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and economic processes in their value chain (supply and demand) affect the farm, and by adopting new insights from scientific research – such as new potato varieties - or from other farmers, they can improve the management of the farm.

Farmers also play a role in the mitigation towards a low-input, energy-efficient and zero-pollution production. A responsible construction and use of **infrastructure, machinery, fertilizers and pesticides** has a positive impact on the **public opinion** and limits the **energy use, leaching, emissions and the overall pollution** (Aneja et al., 2009; Crane et al., 2005; Flammini et al., 2022; Xiao et al., 2022). This, of course, will influence the **biodiversity, water quality, soil- and crop health** and even the overall **climate change** (Heggestad et al., 1977; Parvin et al., 2022) which are all important factors in the production phase of starch potatoes (Gangola et al., 2023). Lastly, it is important to mention that not only the crop production, but also the processing industry will contribute to the total of emissions, waste water and pollution (Chan et al., 2011; Peters, 1972).

A. Social subsystem

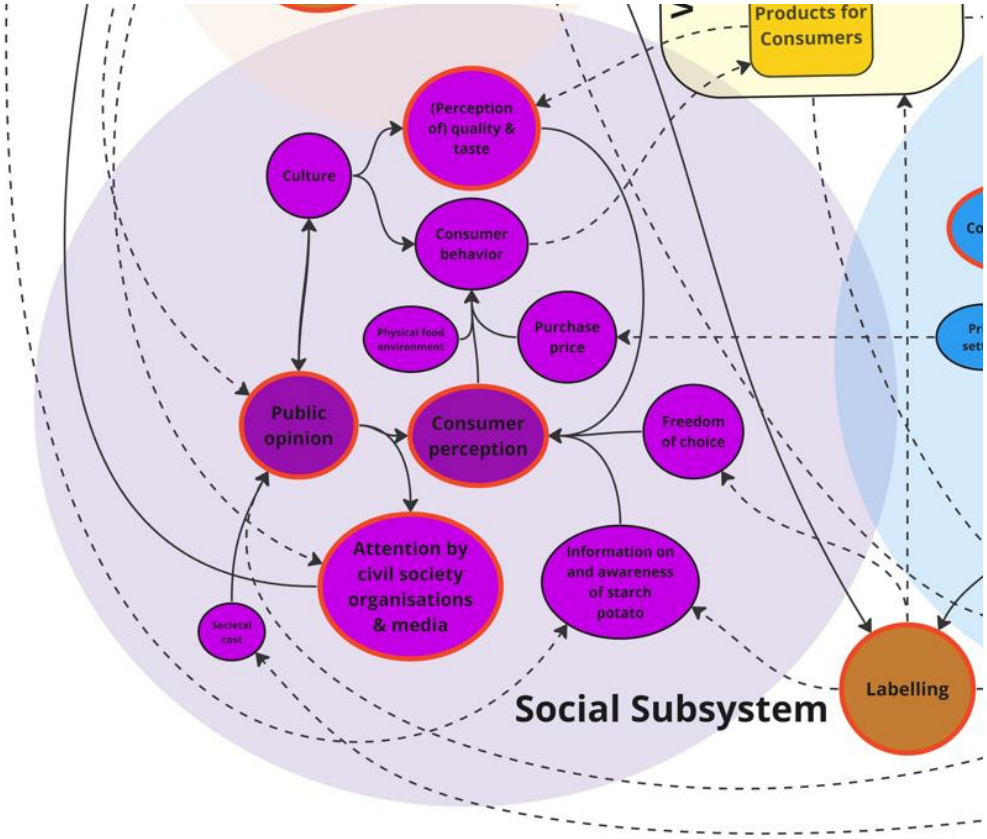

Figure 4: Starch potato - Social subsystem

Starch potatoes have numerous applications, such as food thickener, feed, adhesives and cardboard to name some examples. The **perception** of starch potato products is a central element in the social subsystem and is an important factor in the buying behavior of the consumer (Malik et al., 2014). Studies have shown that lowering the costumers **freedom of choice** will generally lead to a negative perception (Argouslidis et al, 2018). In addition, the **information on and awareness** of (the **safety** of) starch potato products, as well as the **perceived quality and taste** will also play a role in consumer's perception (Brunsø et al., 2002). The latter may change when the production or processing of the starch potato product is changed, but can also be dependent on the cultural context (Krutulyte et al., 2009).

The general public opinion and group conformity can play an important role in the consumer perception (Venkatesan, 1966; Wunderlich & Gatto, 2015). The **public opinion** is a complex phenomenon. It is shaped by various influences, such as the **societal cost** from food production, the use of pesticides and fertilizers (see above), the general **culture**, social action by **civil society organizations** (CSOs) and **media** (Anastasio et al., 1999; Çakmak, 2004; Erikson et al., 1987; Hendriks et al., 2023). This can be problematic because popular media can share incomplete and simplified information (Wunderlich & Gatto, 2015). Moreover, the narratives propagated by media outlets and CSOs not only shape public opinion but also serve as reflections of it (Anastasio et al., 1999). In addition, the public also reciprocally contributes to the construction of cultural norms, it can drive agricultural production towards sustainable investments and even (indirectly) shapes GMO legislation (Aerni, 2009; Wunderlich & Gatto, 2015).

Ultimately, the **behavior of consumers** determines whether or not starch potato products are purchased. This will influence the economic subsystem (discussed above) through supply and demand. Based on the systems mapping workshop, four direct influences are of particular importance for understanding consumer behavior. We already discussed that the perception of the product is a key-factor for consumer behavior. However, studies show that attitudes alone are an insufficient predictor of marketplace behavior due to an attitude-behavior gap (Vermeir & Verbeke, 2008). The demand for potato products is also shaped by **cultural context**. Potatoes are regarded as a versatile and nutritious crop that can be sustainably produced (Birch at al., 2012). In the present global context, the pursuit of a sustainable bioeconomy has emerged as a crucial ambition regarding several pressing factors, including rapid global population growth, the impact of climate change, conflicts, among others (Hinderer et al., 2021). It can thus be expected that cultural context will increase the importance of (starch) potato production in the coming decades. The physical **food environment** is another factor that can explain the gap between consumer perception and behavior (Robinson & Smith, 2002). A (perceived) lack of availability and accessibility deters people from buying starch potato product. The **price** is a final important factor influencing purchasing decisions (Vermeir & Verbeke, 2008). Higher prices tend to discourage consumers, leading them to seek more affordable alternatives or reduce their overall consumption.

B. Economic subsystem

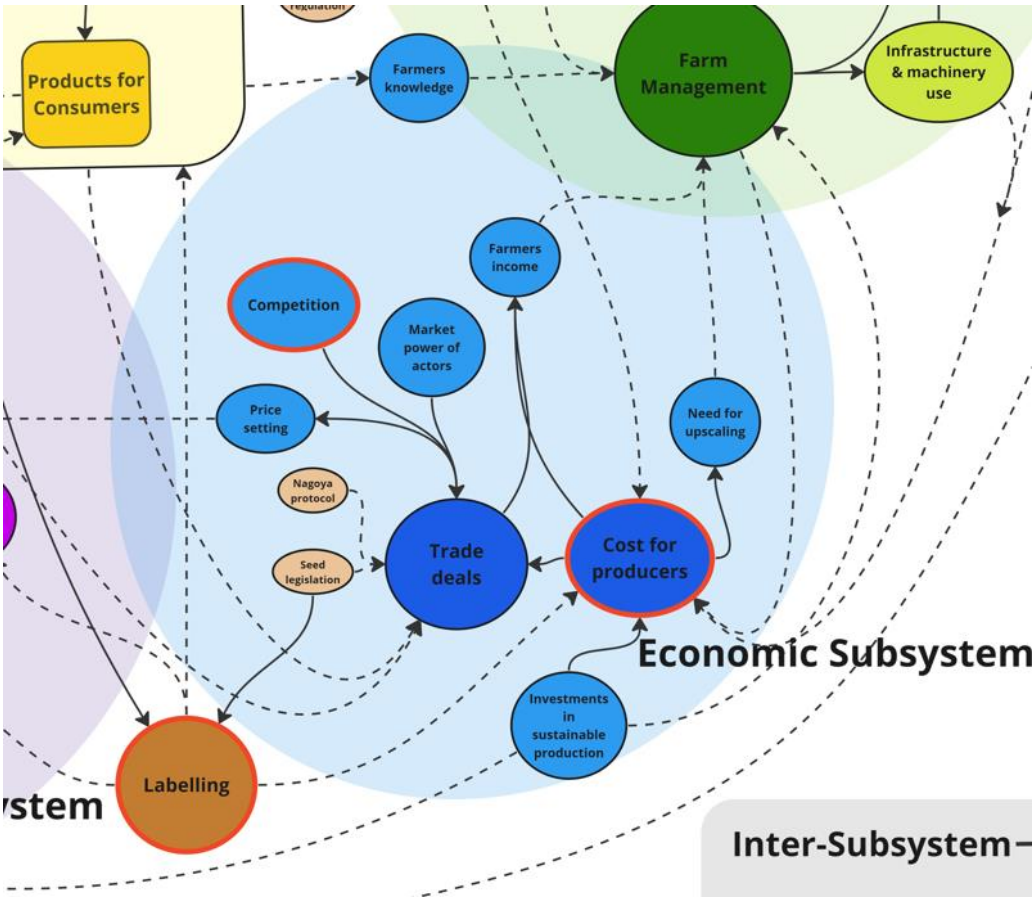

Figure 5: Starch potato - Economic subsystem

Crucial in **the management** of every farm is the **income** of the farmer. Naturally, farmers generate their income by selling their crops. Whether it is local or international, to the starch industry or in the auction, the buyer and seller will have to agree on a certain '**trade dea**l' (e.g. a selling price). Trade deals depends on several factors. First, when the **cost for the production** of the starch potatoes increases due to farm management, investments, energy prices, purchase prices, etc., the farmer will have to increase the price of its crops. An excellent example are the significantly increased food prices in the supermarkets due to the energy crisis in 2022-2023 (IEA, 2022). An important point to consider is that farmers do not necessarily receive adequate compensation for the rising production costs resulting from trade deals (Teagasc, 2022). Consequently, these cost increases can lead to a decline in farmers' income.

The **value chain**'s supply and demand is a second factor that will impact trade deals (MacDonald, 2003). A lower production of a good typically leads to higher prices , while a lower demand will decrease the price. **Competition** is a third factor that will influence trade deals. Again, supply and demand is the driving principle. International production of starch potatoes or the availability of other starch products will create competition, which will decrease the prices (MacDonald, 2003). Fourth, farmers will often join member organizations or cooperatives to increase their **market power**. Participating in these groups will generally lead to better selling prices and a higher income (Tolno et al., 2015).

Finally, trade deals have to be conform to different regulatory frameworks. **Trade legislation** in the EU protects free trade among its member states and removes trade barriers to non-EU markets (*Trade policy and agreements – EU action | European Union*, z.d.). **Seed legislation**

aims to ensure the quality, safety and traceability of plant materials in agriculture and provides legal protection to buyers and sellers (Copeland & McDonald, 2001). The **Nagoya protocol** aims at ensuring greater legal certainty and transparency for both providers and users of genetic resources and sharing the benefits arising from the utilization of genetic resources in a fair and equitable way (Secretariat of the Convention on Biological Diversity, 2015).

When trade deals are ultimately finalized, shaped by these factors, they create a **price setting** that determines the purchase price. However, a certain price setting may also influence trade deals. A reduction in the costs for food production does not guarantee lower food prices (Gerritsen, 2023).

C. Regulatory subsystem

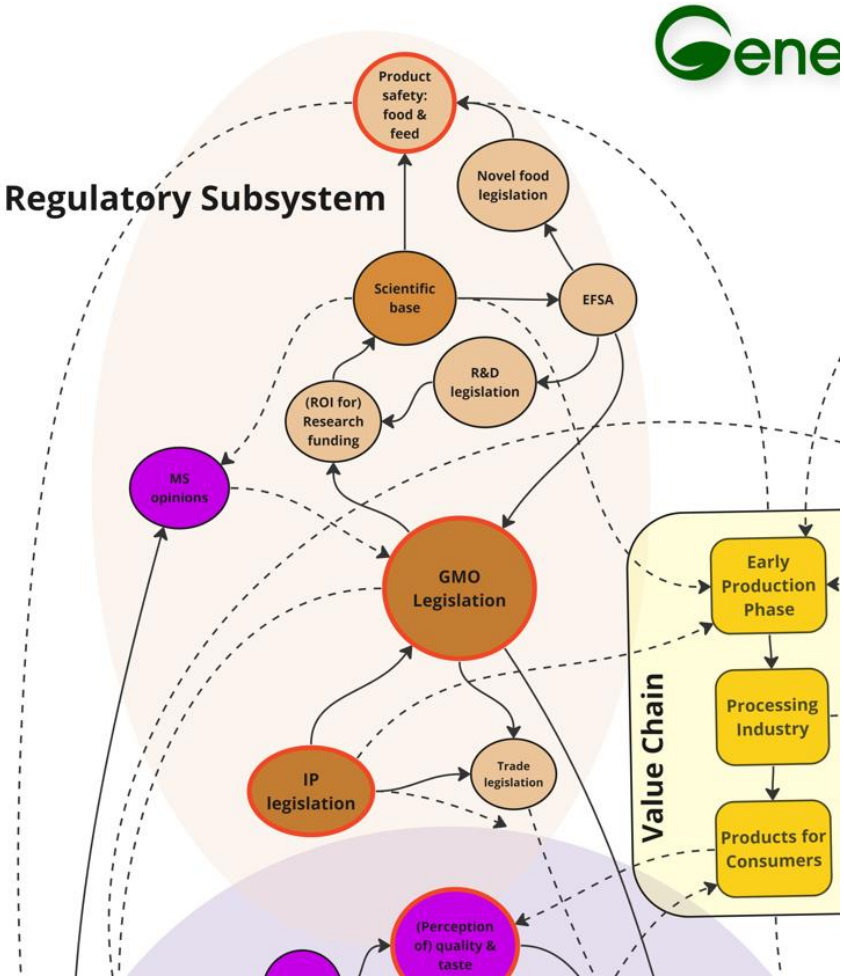

Figure 6: Starch potato - Regulatory subsystem

Various legislations and actors regulate the production of starch potatoes. Central in GeneBEcon is the **GMO legislation**. In EU member states it regulates the cultivation, marketing, and labelling of genetically modified organisms, with strict requirements for risk assessment, authorization, and traceability. It has significant implications across various aspects of research and development, the value chain, labelling, trade legislation, and media and CSOs.

In terms of research and development (R&D), the EU GMO legislation imposes strict regulations and lengthy approval processes, which can hamper innovation and increase costs for companies developing genetically modified organisms. This can result in a reduction in

(return on investments in) R&D funding (Purnhagen & Wesseler, 2019). **Labelling** is a crucial aspect of the EU GMO legislation (*Traceability and labelling*, z.d.). It mandates clear identification of GMOs in food and feed products, enabling consumers to make **informed** choices. The legislation sets a threshold for accidental presence of GMOs in non-GMO products, requiring labelling if this threshold is exceeded. This transparency empowers consumers with a **freedom of choice** but can also create challenges for companies in terms of compliance and potential negative consumer perception of GMOs.

Regarding the **value chain** and the **cost for the producers**, the EU GMO legislation affects the entire process of producing and marketing GMOs via the traceability and labelling requirements (*GMO legislation*, z.d.). The EU wants to ensure that GMO products are appropriately identified and tracked throughout the supply chain. This imposes additional financial and administrative burdens on farmers companies, as they must establish separate systems for handling GMOs and non-GMOs.

The EU GMO legislation intersects with **trade legislation**, particularly in the context of international trade (*GMO legislation*, z.d.). The EU has established strict rules for GMO import authorizations, necessitating comprehensive safety assessments. This can lead to trade disputes with countries that have different regulatory frameworks or lower tolerance for GMOs, resulting in barriers to market access and disruptions in global trade.

Finally, the EU GMO legislation garners significant attention from **media and civil society organizations**. GMOs remain a controversial topic, and the legislation's provisions are often subject to public debate (Wunderlich & Gatto, 2015). CSOs closely monitor the issue, raising concerns about environmental impacts, consumer health, and corporate control of the food system. Media coverage of GMO-related issues, such as controversial approvals or scientific studies, amplifies the public discourse, shaping public perception and influencing policy decisions (Wunderlich & Gatto, 2015).

The impact of **intellectual property rights (IPR)** and patenting was especially much discussed during the workshop. Intellectual property protection allows breeders (in the **R&D** phase of the value chain) to have exclusive rights over their new varieties, which incentivizes innovation and investment in the development of improved seed varieties (*Benefits of IPR*, 2023). However, in the early 2000s, governments, intergovernmental organizations and CSOs expressed their concerns about patent monopoly ownership and control over new varieties of GM foods and feeds (Torrance, 2006). IP and patenting currently still play a big role in the field of GMOs. In international **trade** for example, the United States tends to export fewer GMO crops to countries with strict IPR and patenting legislation (Smith & Kong, 2022). Evidently, both **GMO legislation** and **trade legislation** have to take IPR and patenting into account (*Intellectual property rights and geographical indications*, z.d.; National Academies Press (US), 2000).

GMO legislation affects many different fields. First, the position of each EU member state (MS) influences the legislation. The position of member states on political topics are driven by media attention, CSO actions and the public opinion (Evanega et al., 2022). Environmental NGOs, organic groups and Green parties generally strive for a strict GMO regulatory framework (*Behind the smokescreen*, z.d.). This often stems from concerns about the safety for human consumption and the environments and monopolization of plant varieties by big corporations (Evagena et al., 2022; Torrance, 2006). The agri-biotech industry generally aims for a flexibilization of the legislation as they could contribute to reducing world poverty, hunger and disease (Augoustinos et al., 2010, Belderok et al., 2021).

Of course, this debate is also conducted within **science**. Here too, different voices and results exist (Chu & Agapito-Tenfen, 2022). The **European Food Safety Authority** (EFSA) was set up in 2002 as an impartial scientific agency of the European Union. The agency gives advice on the safety of GMOs to Europe's risk managers i.e. the European Commission and EU Member States, based on independent scientific findings. Naturally, this will affect the novel food, research and development, and GMO legislation. In 2021 for example, the European Commission published a study supported by EFSA which concluded that there are strong indications that the current GMO legislation is not fit for purpose for some NGTs and their products (*EC study on new genomic techniques*, z.d.).

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We welcome your questions, comments and suggestions.

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