Rathenau Instituut

Potatoes are the future

Three scenarios for hybrid potatoes and the global food supply

Report

Authors
Rosanne Edelenbosch and Geert Munnichs

Illustrations
Rikkers Infographics

Cover photo
Hollandse Hoogte

Preferred citation form:
Edelenbosch, R. and G. Munnichs (2020). *Potatoes are the future – Three scenarios for hybrid potatoes and the global food supply*. The Hague: Rathenau Instituut

Preface

No country exports as many seed potatoes as the Netherlands. For generations, the Dutch potato sector has been innovating with new varieties, for example to improve taste or to make them suitable for French fries or crisps. Potatoes are not an easy crop: cultivation has to contend with many diseases and pests, which are combatted using chemical crop protection products. In other countries, yields are often low due to inferior quality seed potatoes and cultivation methods. It would therefore be desirable for innovations in cultivation to also focus on health, sustainability, and food security.

A new breeding method, hybrid potato breeding, makes it possible to adapt varieties faster and bring them onto the market in true seed form. True potato seed is easier to store and transport than the tubers currently used. This innovation offers opportunities for potato cultivation that is more sustainable and can lead to higher yields in differing climate zones and conditions.

In the present study – carried out as part of the NWO's Socially Responsible Innovation (MVI) programme – we outline three scenarios for 2040 showing how the introduction of such an innovation can contribute to an ecologically sustainable and secure food supply, while maintaining a promising revenue model. The scenarios were constructed on the basis of literature research and discussions with and between stakeholders, including farmers, breeders, and environmental organisations. We developed the scenarios further during two workshops and gained various insights into how to deal with the desirable and undesirable aspects of possible future developments.

Our study shows that hybrid potato breeding can only contribute to tackling societal challenges if certain conditions are met. The Rathenau Instituut has been researching such conditions for the integration into society of innovations for a long time and for various sectors. Where the potato sector is concerned, we outline these frameworks with the aid of three main points of consideration.

Stakeholders indicate first of all that the government must create legislation and regulations to ensure that the potato sector remains innovative. Furthermore, the government and the sector must continue to invest jointly in knowledge development. It is also important to continue to involve civil-society organisations. The year 2040 may seem a long way off, but it is necessary to already steer in the desired direction now.

Melanie Peters
Director, Rathenau Instituut

Summary

Potatoes are among the world's most widely cultivated food crops. They are also highly susceptible to diseases, and in poorer countries often only provide a low yield per hectare. Moreover, potato cultivation has a high environmental impact due to the use of chemical crop protection products. A great deal is therefore to be gained by ensuring ecologically sustainable potato cultivation that contributes to global food security.

The Netherlands is a major producer of seed potatoes. Hybrid potato breeding offers the Dutch potato sector new opportunities to help find a solution to these challenges (see box below). A number of Dutch companies are presently working on this technology.

What is hybrid potato breeding and what are its advantages?

Hybrid breeding means crossing "pure" inbreeding lines, thus guaranteeing that the resulting variety has specific characteristics. The advantages are:

- Potato varieties can be adapted more quickly to for example changing climatic conditions or to pathogens.
- Newly developed varieties can become available in the form of true potato seed instead of seed potatoes (tubers).
    a. True potato seed is less susceptible to disease, meaning less use of chemical crop protection products during cultivation;
    b. True potato seed is easier to transport.

Hybrid potato breeding can therefore contribute to sustainability and food security. No use is made of genetic modification in hybrid potato breeding.

Not everyone is convinced that the promises of hybrid potato breeding can actually be fulfilled and it is also questionable what the economic and social consequences will be in the event of successful introduction. For example, the transition from the use of seed potatoes to true potato seed requires the potato production chain to be organised differently, which may have a negative impact on the economically successful Dutch seed potato sector. There are also varying perspectives on the direction in which agriculture and food production should develop.

Three scenarios for the future

The future of hybrid potato breeding is therefore uncertain. In order to imagine and be able discuss that future, the Rathenau Instituut has drawn up three scenarios. These have been utilised to identify the economic, social, and policy conditions that need to be met if hybrid potato breeding is to contribute to more sustainable cultivation and global food security. Consideration has also been given to what constitutes a promising business model for the Dutch potato sector. The three scenarios were discussed with experts, policymakers, and interested parties both inside and outside the sector during two workshops and a number of supplementary discussions.

The three scenarios are assumed to play out in the year 2040. They are based on different narratives, each constructed using four building blocks:

- **Control**: Who holds power within the potato sector?
- **Demand**: What are the main market and consumer trends?
- **Technology**: What are the main technological trends?
- **Focus**: Is the focus on intensive or extensive agriculture?

The scenarios show that societal forces influence the way in which a technological innovation such as hybrid potato breeding takes shape. Conversely, the technology concerned also affects relations within the sector. Understanding the interaction between the two offers pointers for guiding this innovation in the right direction.

Each scenario assumes the successful introduction of hybrid potato breeding and is based on a trend that is already apparent:

- The “Global Duopoly in 2040” scenario is in line with the current trend in agriculture towards **increasing scale** and **intensification**;
- The “Circular and High-Tech in 2040” scenario is inspired by the vision of **sustainable intensification**;
- The “Diversified Markets in 2040” scenario is based on the idea of **participatory breeding**, in which farmers are involved in the development of new varieties.

The three scenarios are briefly described below on the basis of the four building blocks.

Scenario 1: Global Duopoly in 2040

In 2040, two multinationals dominate the potato sector. The world population has increased dramatically and potato products are extremely popular in many countries. This scenario makes use of the following four variable building blocks:

- **Control**: Two large multinationals control and dominate the potato sector worldwide. They determine which potatoes are eaten.
- **Demand**: Demand for potatoes has increased sharply worldwide, but the importance of the European consumer market has declined.

- **Technology**: The multinationals make pragmatic choices regarding the use of potato seed or seed potatoes, genetic modification or hybrid breeding, and crop protection products.
- **Focus**: Large-scale potato production, in which yield per hectare is the leading factor, contributes to world food security, but at the expense of the environment.

Scenario 2: Circular & High-Tech in 2040
In 2040, the Netherlands has been hit hard by global warming. A large proportion of Dutch agricultural land has had to make way for nature. This scenario makes use of the following four variable building blocks:

- **Control**: The Dutch government imposes strict ecological sustainability conditions on companies in order to make the economy circular. The traditional Dutch seed potato sector has disappeared.
- **Demand**: Dutch consumers pay more for tasty, healthy, and varied food. Dutch potato growers focus mainly on local markets.
- **Technology**: Dutch agriculture relies heavily on technological innovation in order to deal with problems caused by climate change. Poorer countries cannot keep up with these technological developments.
- **Focus**: More space for nature in the Netherlands means that potato growers need to produce as much as possible on the limited area of agricultural land that is available.

Scenario 3: Diversified Markets in 2040
In 2040, patents on the natural properties of plants have been abolished worldwide. Public organisations ensure the accessibility of suitable potato parent lines.
This scenario makes use of the following four variable building blocks:

- **Control**: Breeders worldwide utilise hybrid breeding to develop regionally adapted varieties. The Dutch seed potato sector produces only for the local market. The Netherlands trades worldwide in know-how about breeding and integrated potato production chains.
- **Demand**: Consumers' interest in local food has increased. The processing industry demands uniform varieties.
- **Technology**: Innovation in the potato sector focuses mainly on the natural breeding of varieties.
- **Focus**: A large part of global production small scale and diversified, utilising local infrastructures. Potatoes for the processing industry are produced in bulk by larger farming companies.

Three lessons from the scenarios
The scenario workshops and discussions, and our analysis of them, yield the following three scenario-transcending lessons. They offer guidance for hybrid potato breeding to contribute to an ecologically sustainable and secure food supply, while maintaining a promising business model for the Dutch potato sector.

Lesson 1: Legislation and regulations for the development of new varieties
It is important to maintain an innovative market for breeders so that new potato varieties that contribute to food security in a sustainable manner continue to be developed. Governments must guarantee, through national and international legislation and regulations, that:

- breeders retain access to genetic material and new knowledge;
- breeders can make use of a variety of breeding techniques; and
- new potato varieties on the market are subject to protection, so that it is worthwhile for breeders to invest in them.

Governments can ensure this by:

- establishing and maintaining gene banks;
- continuing to fund public knowledge institutions so that a common knowledge base is maintained; and
- retain provisions such as plant breeders' rights that allows breeders to protect and monetize on new varieties.

Lesson 2: Ensure diversity of genes, varieties, and also cultivation systems
The different ways in which hybrid breeding is used in the various scenarios show that breeding technology alone does not offer a solution to issues of sustainability and food security.

The technology offers opportunities both for the unlocking of a broad genetic diversity and for developing varieties that are identical apart from the type of built- in resistance genes. The technology can thus be utilised in various breeding strategies and cultivation systems. It is important to promote a diversified approach. In order to ensure the societal embedding of the technology, careful consideration must be given to the *combination* of variety, cultivation system, and production chain. In the view of the parties involved, the government is the appropriate party to set conditions so that hybrid potato breeding actually helps to tackle societal challenges.

It is therefore up to the government to encourage market players:

- when developing new varieties, to build in disease resistance in a sustainable manner, for example by stacking resistance genes (i.e. various different resistance genes in a single variety);

- to utilise mixed breeding systems, with different varieties in the field, thus reducing the rate of diseases breaking out; and
- to focus on both broadly applicable and niche varieties, aimed at both short-term (yield security) and long-term goals (which ensure continued access to broad genetic diversity).

Lesson 3: Invest in the know-how position of the Dutch potato sector
The three scenarios show that the leading position of the Dutch potato sector is not self-evident. However, the sector's strong knowledge position can form the basis for a new business model in the form of the export of know-how. The sector can thus make a substantial contribution to optimising cultivation in other countries. This requires not only high-quality potato varieties but also knowledge of local production conditions and development of local potato infrastructures. With its knowledge of potato breeding, potato cultivation, and potato production chains, the Dutch potato sector can acquire a pivotal position in local production chains.

In order to continue to play a significant international role, it is therefore important for the Dutch potato sector and the Dutch government to continue to invest in the development of both basic and applied knowledge.

Conclusion
Hybrid potato breeding could play an important role in the quest for ecological sustainability and world food security. However, it is not a foregone conclusion that this will actually happen. A technological innovation such as hybrid potato breeding does not follow a single possible path of development. How such innovation takes shape in actual practice is determined by the economic, social, and policy decisions made. Within certain margins, companies can choose how sustainably they wish to operate and what contribution they wish to make to the world food issue. These choices are partly driven by the public pressure that civil-society organisations exert on companies, by regulations, and by government policy regarding knowledge and innovation. This means that companies, civil-society organisations, and the government all need to take action.

Contents

1 Introduction

Potatoes are among the world's most widely cultivated food crops. They are also highly susceptible to diseases, and in poorer countries often only provide a low yield per hectare. Moreover, potato cultivation has a high environmental impact due to the use of chemical crop protection products. A great deal is therefore to be gained by ensuring ecologically sustainable potato cultivation that contributes to global food security.

1.1 Background

The Netherlands is a major producer of seed potatoes. Hybrid potato breeding offers the Dutch potato sector new opportunities to help find a solution to these challenges: hybrid potato breeding (see box below). A number of Dutch companies are currently working on this technology.

What is hybrid potato breeding and what are its advantages?

Hybrid breeding means crossing "pure" inbreeding lines, thus guaranteeing that the resulting variety has specific characteristics. The advantages are:

- Potato varieties can be adapted more quickly to for example changing climatic conditions or to pathogens.
- Newly developed varieties can become available in the form of true potato seed instead of seed potatoes (tubers).
    a. True seed is less susceptible to disease, meaning less use of chemical crop protection products during cultivation;
    b. True seed is easier to transport.

Hybrid potato breeding can therefore contribute to sustainability and food security. No use is made of genetic modification in hybrid potato breeding.

The potatoes on your plate are the result of a complex production chain influenced by all kinds of forces, including the development of new technology, but also policy, changing climate conditions, and the international food market. The question is how, within that interplay of forces, the promises of hybrid potato breeding can be fulfilled.

For the Rathenau Instituut, an important question is under what conditions a technological innovation such as hybrid potato breeding can actually contribute to a secure and sustainable food supply.

1.2 Method

The future of hybrid potato breeding is therefore uncertain. In order to imagine and discuss that future, we have drawn up three future scenarios. The scenarios and the choices they reveal are a contribution to the broader political and societal debate on the future of agriculture.

The three scenarios have been utilised so as to identify the social, economic, and policy conditions that need to be met if hybrid potato breeding is to contribute to more sustainable cultivation and global food security. Consideration has also been given to what constitutes a promising business model for the Dutch potato sector.

The scenarios were discussed with experts, policymakers, and interested parties both inside and outside the sector, during two workshops and a number of supplementary discussions.

1.3 Context

This study is part of the research programme on Socially Responsible Innovation (MVI) by the Netherlands Organisation for Scientific Research (NWO), which focuses on the social significance and ethical acceptability of technological innovations. The present report describes the findings of one of three studies conducted within the Potarei project, in which the Rathenau Instituut collaborated with Wageningen University & Research, the University of Groningen, and the Solynta hybrid potato breeding company (see Appendix 1).

2 Innovation for an important food crop

For a better understanding of the possibilities offered by hybrid potato breeding, in this chapter we sketch a picture of the potato crop. In addition, we describe the potential for innovation in the potato sector.

2.1 Introduction

Along with maize, rice and wheat, potatoes are one of the world's most widely cultivated food crops (FAO, 2019). They form the basis for French fries, crisps, and the traditional staple of potatoes, meat, and vegetables in The Netherlands. Potatoes feature regularly on the menu in many countries, in all kinds of forms. Potato is also an important raw material for the starch industry. The global chips market is growing by almost 4% annually (IMARC group, 2019), and in emerging markets such as China demand is growing even faster (Van der Boom, 2019).

But potatoes are not an easy crop. Cultivating them involves battling many diseases and pests, such as potato blight (Phytophthora). In Western countries, numerous chemical plant protection products are therefore used, which has a high environmental impact. In developing countries, the yield per hectare is often low, due to the use of poor starting material and sub-optimal cultivation methods (Thomas-Sharma et al., 2015). There is therefore a pressing need for potato cultivation that is more sustainable and that can produce higher yields in differing climate zones and conditions.

In the Netherlands a lot of money is being invested in the know-how needed for future-proofing potato cultivation (NOS, 2016). The Netherlands has an economic interest as the biggest player on the world market for seed potatoes – the tubers from which potatoes grow. In 2017 the Netherlands exported more than 800,000 tonnes of seed potatoes (NAO, 2019), representing 60% of the worldwide export market for certified seed potatoes (AGF, 2018). At the same time, this share is only a fraction of the total seed potato market, because the vast majority of seed potatoes used by farmers worldwide are not certified.

2.2 From tubers to a national icon

Seed potatoes are propagated in a number of steps by seed potato growers. Subsequently, farmers who grow ware potatoes allow seed potatoes to grow into plants bearing fully grown potatoes suitable for consumption or processing in the starch industry.

The advantage of propagation using tubers is that every potato has the same genetic composition. Potatoes that are uniform in terms of size, colour, flavour, and other properties are convenient for factory processing, for example.

The use of seed potatoes also has disadvantages, however: they are heavy and bulky for storage and transport, and are vulnerable to spoilage. In addition, each step in breeding increases the risk of the potatoes involved being affected by diseases. Potato growers therefore make extensive use of chemical plant protection products. In 2016, the potato sector accounted for 40% of the total use of crop protection products in Dutch agriculture (CBS, 2018).

Breeders therefore carry out a lot of research into new varieties that are resistant to diseases, thus reducing the need for chemicals. However, in traditional breeding, it can take up to ten years before a new variety can be brought to the market. Crossing parent lines produces large numbers of different offspring. To select a potato plant with the right combination of desired properties, up to a hundred thousand plants need to be tested in the field.

In the case of potatoes, for a long time it was considered impossible to use hybrid technology due to the characteristics of the hereditary material of the potato. That changed in 2011 when researchers of the Solynta company published an article about a technological breakthrough in hybrid potato breeding (Lindhout et al., 2011). In 2014, Solynta was consequently proclaimed a “national icon” by the Dutch Ministry of Economic Affairs. According to the Ministry, with this “pioneering technology” the company had made it possible to increase the nutritional value of potatoes and to grow different types.[1] In 2017, the company again received an injection of capital from various funds and shareholders (Verbeek, 2019). Other companies are now also working on hybrid breeding (Engwerda, 2019). The Bejo vegetable seed company, for example, recently launched its first potato hybrid, the Oliver F1 (Bejo, 2019).

1 See “*Hybride aardappel – Een nieuwe veredelingstechniek toegepast op aardappelzaad.*” Consulted on 4 December 2019 at www.nationaleiconen.nl/bekroonde-nationale-iconen/hybride-aardappel.

2.3 Promises of hybrid breeding

Hybrid breeding works on the basis of “pure” potato parent lines, which only have a single variant of all genes. As a result, a parent line always passes on the same gene variants to its offspring. This method is promising in two respects:

1. The use of pure parent lines makes it possible to improve varieties **faster and in a more targeted manner**. “Backcrossing “enables specific traits to be added to the parent lines. New traits may involve resistance to disease, but also taste, colour or shape, a higher yield, or drought resistance. This way, hybrid potato breeding can efficiently contribute, for example, to more sustainable potato cultivation than traditional breeding. Hybrid potato breeding still needs to be followed by research on the stability and characteristics of the variety, just like traditional breeding and genetic modification.

2. A second promising aspect concerns the possibility offered by hybrid breeding for cultivating potatoes directly from seed. The fact that hybrid seed shows little genetic variation means that it produces plants and **potatoes that are uniform**. Moreover, potato seed is not susceptible to viral diseases and is **easier to transport and store** than seed potatoes. It could be distributed worldwide by post, for example, making it more readily available to small farmers in remote areas. The vast majority of global potato production takes place for local markets in poorer countries. The use of these new potato varieties can have advantages as regards the environment and food security in such situations.

In Table 1 we compare different methods to improve potatoes. Hybrid breeding works on the basis of natural cross-breeding, as does traditional cross-breeding. In the case of genetic modification, existing varieties are altered by actively modifying the genetic material. The legal requirements specific to genetic modification do not therefore apply to hybrid breeding. Another advantage of hybrid breeding compared to existing genetic modification techniques is that potatoes can be grown from true seed.

Table 1 Three ways to improve potato varieties

	How does it work?	Improving potatoes	Trade in true potato seed	European protection rights		Trading rights
				Variety	Process	
Traditional breeding	New varieties are developed by crossing existing varieties, followed by years of selection research.	Introduction of new traits takes at least 10 years.	No, not marketable because each individual seed is different.	• Breeder's rights*, costs for developers: tens of thousands of euros. • Breeders can apply for a patent on new traits in plants.	The crossing of varieties is a natural process and does not fall under EU GMO patent legislation.	• Seed potatoes are assigned to a quality class by the Dutch General Inspection Service. • Each country has its own plant health requirements for seed potatoes.
Hybrid breeding	New varieties are developed faster by crossing "pure" parent lines, which have only a single gene variant for all genes, followed by years of research.	The promise is that new traits can be introduced in less than five years. However, parent lines with suitable traits will first need to be developed.	Yes, true potato seeds of pure parent lines are uniform and can be used as starting material.	• Breeder's rights*, costs for developers: tens of thousands of euros. • Breeders can apply for a patent on new traits in plants.	The crossing of varieties is a natural process and does not fall under EU GMO patent legislation.	• Regulations for true potato seed are still being developed. • In many countries there are not yet any regulations.
Genetic modification, including CRISPR-cas9	Alteration of existing varieties through active intervention in genetic material, followed by years of research into traits and stability.	Even if the DNA intervention takes only a few days, the entire process from gene identification to field research takes longer. The DuRPH project, in which existing varieties were given multiple resistance to potato blight, took a total of 10 years.	No, not marketable because each individual seed is different.	• Falls under EU's GMO regulations. To be accepted, the developer must demonstrate the safety of the product. Cost: millions of euros. • Breeders can apply for a patent on new traits in plants.	Genetic modification is not a natural process and a patent can be applied for.	• Seed potatoes are assigned to a quality class by the Dutch General Inspection Service. • Each country has its own plant health requirements for seed potatoes.

* Breeder's rights can be applied for if the variety is new, distinguishable, uniform and stable.
With plant breeders' rights, the breeder has the exclusive right to trade seed potatoes and (true) seed (Louwaars et al., 2009)

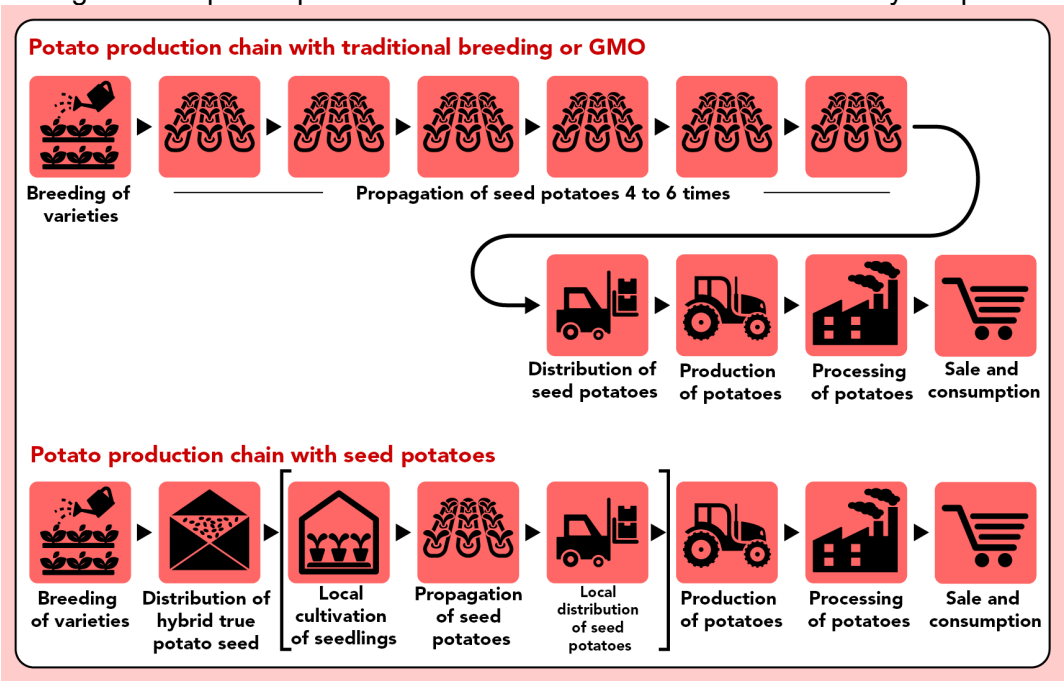
2.4 Uncertainties regarding potential impact

Hybrid potato breeding holds great promise. To what extent this innovation will actually contribute to environmental sustainability and food security is uncertain, however. For socially responsible use of hybrid potato breeding, various uncertainties need to be taken into account.

1. Firstly: to what extent can the **technological promises** be fulfilled? There are doubts within the potato sector as to whether potatoes can in fact be grown directly from seed, as indicated in earlier research (Beumer & Edelenbosch, 2019). True potato seeds are asserted to be too vulnerable to grow in the open field. Potato seed could still be used to produce seed potatoes locally, but that would require a new, local potato infrastructure, with, for example, farmers cultivating seed potatoes from seed (for other farmers).

2. It is also questionable what the **economic and social consequences** will be in the event of successful introduction of hybrid potato breeding. The transition from the use of seed potatoes to true potato seed requires the potato production chain to be organised differently (see Figure 1), which may have major consequences for the economically successful Dutch seed potato sector. It remains to be seen which parties within the production chain will benefit from this innovation within the sector as currently organised, and what that will mean for small farmers in Africa, for example. Will it indeed lead to more sustainable cultivation, with less use of chemical crop protection products, higher yields, and worldwide food security?

Figure 1
Changes in the potato production chain in the event of transition to hybrid potato seed.



Finally, **opinions differ as to what constitute desirable developments** for the future of agriculture and food production. Development of hybrid potato breeding involves many of the same social issues that also play a role in debate on genetic modification in agriculture, for example:

- the dependence of farmers and consumers on large multinational companies;
- the accessibility of genetic material;
- the affordability of potato seed and seed potatoes; and
- the attention given to ecological sustainability in the development of new varieties, which require new production methods and alter the working methods within the production chain.

3 Drawing up the scenarios

This study utilised three scenarios so as to identify economic and policy conditions that need to be met if hybrid potato technology is to contribute to more sustainable cultivation and global food security.

3.1 Methodology

It goes without saying that “the” future cannot be predicted. We live in too complex a world, in which far-reaching changes can take place in only a relatively short period of time. Future scenarios are a way of stimulating the imagination and structuring discussion of wishes and expectations for the future. They broaden our horizon and increase insight into the possible future course of relevant developments, the relationships between them, and their economic and social effects (Dammers et al., 2013; Van Duijne & Bishop, 2018).

The three scenarios were drawn up on the basis of reports on the Dutch potato sector, various scenario studies in the field of agriculture and nutrition, and 19 interviews with stakeholders from inside and outside the Dutch potato sector. We talked to breeders, seed potato farmers, trading companies, civil-society organisations, experts, and policymakers about their expectations and wishes regarding the future of hybrid potatoes. Appendix 3 lists the sources used.

Two scenario workshops were also arranged:

- During the first of these, the scenario narratives developed on the basis of literature and interviews were explored further;
- During the second workshop, lessons were drawn regarding the conditions for sustainable use of hybrid potato breeding that makes a substantial contribution to global food security. The business model of the Dutch potato sector was an important focus, because it too is a prerequisite for successful innovation.

The workshops were attended by stakeholders from inside and outside the sector, experts, and policymakers. Not all the invitees were able to attend, so additional consultations were held with some of them about the main results of the workshops.

During this process, the Rathenau Instituut was advised by the Valorisation Panel for the MVI Potarei project, consisting of representatives of the agri-food and potato sector, ministries, knowledge institutes, and civil-society parties. A special guidance

committee comprising of foresight experts provided advice on how to draw up the scenarios and design the workshops (see Appendix 2).

3.2 Building blocks of the scenarios

For the purposes of this study, three future scenarios were drawn up for the year 2040. These are based on potential economic and social developments that can have a major impact on (global) potato cultivation and the food supply, but with a large degree of uncertainty. It is precisely developments that may have a great deal of impact but which also involve a high degree of uncertainty that stimulate the imagination and broaden the horizon. Four such developments were selected as variable building blocks for the scenarios:

- **Control**: Who holds power within the potato sector?
- **Demand**: What are the main market and consumer trends?
- **Technology**: What are the main technological trends?
- **Focus**: Is the focus on intensive or extensive agriculture?

The scenarios aim to clarify the mutual influence between introduction of hybrid potatoes and the above economic and social developments. In each scenario, these four questions have been answered differently – the starting point for a different narrative for each of them. Each scenario assumes the successful introduction of hybrid potato breeding on the (global) market. The introduction of hybrid potatoes in itself is therefore not one of the building blocks. The rest of this section explains the four building blocks of the scenarios in greater detail.

3.2.1 Building block 1: Control

Who has the power?
The Dutch potato sector is the world's biggest exporter of seed potatoes. The question is whether Dutch companies can continue to play the same role in the future. In 2020, the Dutch seed potato sector is dominated by trading companies both large and small, the majority of which are from the Netherlands. Breeding is carried out by breeding companies that form part of the trading companies and also by "hobby breeders". Together with the processing industry, the trading companies determine to a large extent what kind of seed potatoes are propagated by the seed potato farmers. If hybrid breeding becomes successful, it will have an impact on the way the Dutch potato sector is organised.

Hybrid breeding offers trading companies new opportunities for exporting clean, high-quality potato varieties to countries where farmers now make use of low-quality seed potatoes, or to which seed potatoes cannot be exported. A large-scale switch to the use of hybrid true potato seed can also have major negative consequences for control of the market, both for the seed potato growers and for the position of the Dutch seed potato sector on the world market. This switch offers business models for new players (Bronson, 2015). Being able to grow potatoes from true potato seed can be interesting, for example, for large multinationals in the seed industry which have a different business strategy to that of the Dutch trading companies.

The Dutch seed potato sector is characterised by a relatively open innovation culture. What is unique for the Netherlands is the contribution of hobby breeders who cultivate new varieties in their own fields, thus contributing to the genetic variety of potato varieties (Almekinders et al., 2014; De Vriend & Lammerts van Bueren, 2014). When new players enter the market that can shield off the use of hybrid breeding and genetic material, this could inhibit the sector's current capacity for innovation.

What also matter are the purposes for which hybrid potato breeding is utilised. With hybrid potatoes, Solynta aims to contribute to food security, and the company also focuses on the African market.[2] Other companies may make different choices in this regard. Whoever has control of potato cultivation will exert influence on breeding and on how the potato production system is organised, on the extent to which production is sustainable, and on the type of potatoes grown and consumed locally.

3.2.2 Building block 2: Demand

What are the main market and consumer trends?
An important factor for the future of hybrid potato breeding is how the international potato market develops. On the one hand there is the question of what the future demand for hybrid true potato seed will be from the current purchasers of seed potatoes, namely potato farmers. How does hybrid seed fit into the informal seed potato markets dominant in a large part of the world? Will small farmers in Africa really benefit from clean hybrid seed? Will they be able to afford it? Who will organise distribution locally?

In addition, global consumer demand for potato products is changing. Does a growing world population also mean that more potatoes will be eaten? Global consumption of French fries has grown strongly over the past ten years, and is expected to increase in

2 See the Solynta website: http://solynta.com/index.php/sustainable-food/. most recently consulted on 11 December 2019.

emerging markets such as Brazil and China (Potato Business, 2018). At the same time, Western consumers are increasingly concerned with a healthy diet, high quality, varied taste, and the origin of their food (Van Rijswick, 2016). The ever-increasing technologisation and industrialisation of agriculture and food production prompts a desire among some consumers for “naturalness” and “authenticity”. In line with this, there is a growing demand for organic farming and regional products. The position of hybrid breeding in all this is open to question. Will there be a greater need for niche products such as the Dutch “Eigenheimer” variety? Or will potatoes in fact become an even larger bulk product that is easier to process for industrial use and for efficient cheap food products such as snacks? Each of these factors can have consequences for the (international) potato market, and each requires potato breeders and growers to adapt to changing and differentiated demand.

3.2.3 Building block 3: Technology

What are the main technological trends?
The use of high-tech methods in agriculture often meets resistance from members of the public. Sometimes this concerns a specific technology, such as genetic modification (GM) (De Bakker et al., 2011). In the eyes of the law, hybrid technology is not a GMO technology[3] because it makes use of natural cross-breeding, but developments in the field of genetic modification may be relevant for hybrid breeding. For example, the DuRPh project at Wageningen University & Research (WUR) shows that a potato resistant to potato blight can also be developed more quickly by means of genetic modification (WUR, 2015). The potato sector has so far been reluctant to make use of this technology because the authorisation procedure for bringing GMOs onto the market and for the cultivation of food crops is costly, and earlier studies have shown that there is considerable public resistance. But this may change in the future (Mampuys and Stemerding, 2010; Engwerda, 2015).

Genetic modification technology can also be employed to enhance our knowledge regarding breeding, both in terms of the inheritance of traits in different generations and how certain DNA sequences are related to certain traits. Technologies such as CRISPR-Cas9 are then not used to develop new varieties for the market but as a laboratory tool to develop know-how or to speed up analysis of a newly developed variety.

3 In the case of genetically modified organisms (GMOs), the DNA has been deliberately and specifically adapted. For crops subject to GMO guidelines, a risk assessment must be carried out of their immediate and long-term effects on human health and the environment. Such crops must also be monitored, traceable, and provided with a GMO label (Habets et al., 2019).

The technologisation of agriculture may well continue in other areas too. Developments in the field of GPS, ICT, sensor technology, robotisation, vertical agriculture, and 3D food printing can contribute to more sustainable cultivation and to food production in urban areas (De Wilde, 2015).[4] This could reduce the need for new varieties and therefore for hybrid potato breeding in more sustainable agriculture. This also applies to developments such as the cultivation of mini-tubers, which are less vulnerable to diseases and easier to transport than traditional seed potatoes. These parallel technological trends influence the market as well as consumer choice and raise questions with regard to the future of potato production and the role hybrid breeding can play in it.

3.2.4 Building block 4: Focus

Intensification or extensification?
In recent decades, increasing scale has been an important trend in arable farming, with an emphasis on cost reduction and increased production per hectare (ABN AMRO, 2010). This has often been accompanied by serious pressures on the environment that threaten the soil, water, and the future of agriculture (Grinsven, van Eerdt et al., 2014). Exploratory studies by the Food and Agriculture Organization (FAO) reveal a growing global scarcity of natural resources, such as soil and water, in the near future, with the risk of increased competition for these resources, and overexploitation (FAO, 2017).

This raises the question of the extent to which a food production system focusing on reducing costs and increasing yields per hectare is compatible with the pursuit of more sustainable agriculture. In the course of debate on this subject, regular reference is made to “land sharing” versus “land sparing” (Bennett, 2017). Is intensive agriculture – with an emphasis on high yields per hectare – desirable, so that less land is needed (and land is “spared”)? Or should agriculture instead be extensified, thus devoting more space to natural processes on farmland, so that it is less damaging to the environment and biodiversity (“sharing” the land)?

Hybrid potato breeding offers opportunities for both intensification and extensification of agriculture. But because both these strategies require different choices, they also require different use of hybrid technology.

4 See https://www.wur.nl/nl/Dossiers/dossier/dossier-precisielandbouw.htm.

3.3 From building blocks to scenarios

Each of the three scenarios explained below has its own narrative with its own internal tensions. The Rathenau Instituut first developed three basic scenarios as a starting point; these were then further elaborated during the two scenario workshops.

The first scenario – “Global Duopoly in 2040” – is in line with the current dominant trend in agriculture towards increasing scale and intensification of farming, as described, for example, by Levidow (2015).

The second scenario – “Circular and High-Tech in 2040” – is inspired by the ecomodernist vision of sustainability, characterised by sustainable intensification; this is advocated, for example, by Boersma (2018).

In the third scenario – “Diversified Markets in 2040” – the focus is on public access to genetic resources, allowing farmers to contribute to the breeding of new varieties suited to local conditions. More information about this can be found in *Plant Breeding and Farmer Participation*, for example (FAO, 2009).

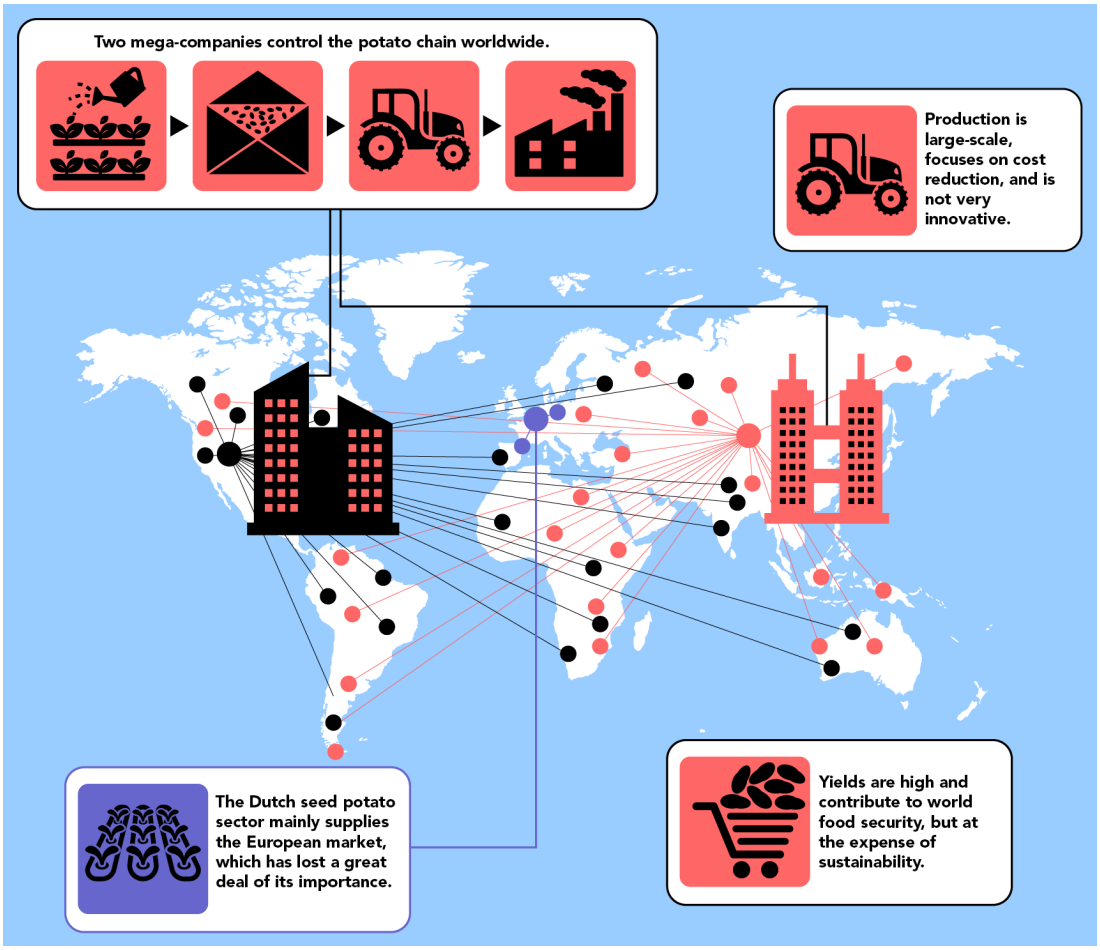
4 Future scenarios for hybrid potatoes

4.1 Scenario 1: Global Duopoly in 2040

In 2040, two multinationals dominate the potato sector. The world population has grown enormously and potato products are extremely popular in many countries. This scenario makes use of the following four building blocks:

- **Control**: Two large multinationals control and dominate the potato sector worldwide. They determine which potatoes are eaten.
- **Demand**: Demand for potatoes has increased sharply worldwide, but the importance of the European consumer market has declined compared to other parts of the world.
- **Technology**: The multinationals make pragmatic choices regarding the use of true potato seed or seed potatoes, genetic modification or hybrid breeding, and crop protection products.
- **Focus**: Large-scale potato production, in which yield per hectare is the leading factor, contributes to world food security, but at the expense of the environment.

Figure 2 Visualisation of the “Global Duopoly in 2040” scenario



Multinationals dominate the world market

It is 2040, and potatoes are big business. Major population growth in Africa and Asia and the increasing popularity of potatoes – and of potato products such as French fries – make investing in bulk potato production a profitable enterprise.

Two large multinationals together control almost 80% of the global trade in potatoes. After achieving a definite breakthrough in hybrid potato breeding in 2021, Solynta was taken over by a large seed and chemicals company. Because of its experience with other seed crops, this company also sees opportunities for hybrid true potato seed, which is easy to transport and can be grown in bulk. In 2031, this company in turn became part of the mega-multinational WorldSeed, which is engaged in a fierce global battle with rival multinational Ali Dow.

Shifts in global potato markets
Aided by highly efficient, large-scale cultivation of bulk potatoes, global potato production has almost doubled. The mega-companies and the global food chains they control make a substantial contribution to feeding the world's 9.7 billion inhabitants.

Potato yields in Ethiopia, Kenya, and Uganda are now so high that that region is regularly referred to as "New Idaho". However, many small farmers elsewhere in Africa and in Latin America still have to rely on marginal land and are unable to afford potato seed and the related infrastructure. They cannot compete with the highly efficient, large-scale bulk producers and produce only for their own small local market and their own consumption.

As the result of a combination of factors, the European consumer has become less important. The European Patent Office does not grant patents on plants developed in a natural manner. As a result, Europe is not an interesting market for the mega-companies. In addition, European consumption of bulk potatoes has fallen sharply over the past 30 years due to a shrinking population and growing consumer preference for traditional, regionally produced potato varieties grown by a number of Dutch and German trading companies. These regional varieties offer consumers better taste and enjoyment than the processed products on which WorldSeed and Ali Dow base their profits. The number of trading and breeding companies in the Netherlands is much smaller than it used to be. Although the Dutch seed potato sector still produces a large proportion of Europe's seed potatoes, the country's position as the biggest seed potato exporter on the world market has fallen victim to the power of bulk production by the multinational mega-companies.

A pragmatic innovation strategy
The two mega-companies own a repository of potato parent lines, i.e. the mother and father plants from which new hybrid varieties can be developed. In addition, they utilise genetic modification techniques such as CRISPR-Cas to modify the genetic material in such a way that potatoes become resistant to diseases, for example. They have sufficient financial clout to pay for expensive market authorisation procedures for potatoes that have been genetically modified. Patents are used to block other breeders from accessing the technologies and varieties that have been developed.

A conservative innovation strategy is sufficient for both companies. They buy up small, innovative start-ups, but a great deal of innovation is "left on the shelf". The two companies have only a limited interest in a greater diversity of varieties, because that makes the cultivation and processing of potatoes more complex. The result is a limited range of high-yielding varieties for the starch industry, the processing industry, and the fresh produce market.

The two companies maintain tight control over a fully integrated potato production chain. Hybrid true potato seed is easy to transport worldwide, which is why the two companies produce it at a single central location, but propagate and cultivate potatoes from it close to the various local markets. Because cultivating potatoes from true seed requires the precise use of fertiliser, spraying and disease control, they supply the seed together with the necessary technical infrastructure. Based on the data this allows them to collect, the mega companies advise farmers and optimise production. They subsequently buy up the potatoes produced in order to process, package, and sell them themselves. The limited profit margin on potatoes forces growers to operate on a large scale, although they are virtually certain of a good harvest and an income.

In addition to old-fashioned crisps and French fries, a varied range of fantasy potato products is being produced, particularly in China and North America. Despite the use of only a limited number of varieties, there is therefore sufficient choice for the consumer.

Ecological sustainability under pressure
The pursuit of high yields and cost reduction by WorldSeed and Ali Dow is detrimental to the environment. For the large-scale cultivation of potatoes, they make use of monocultures, which has led to a worldwide reduction in crop diversity and soil fertility. Because the deployment of chemical plant protection products is part of their business model, there is only limited investment in more robust varieties. The mega-companies are also successful in lobbying against international regulations to reduce the use of such plant protection products. The argument that these products are needed in order to feed the growing world population plays an important role in this regard.

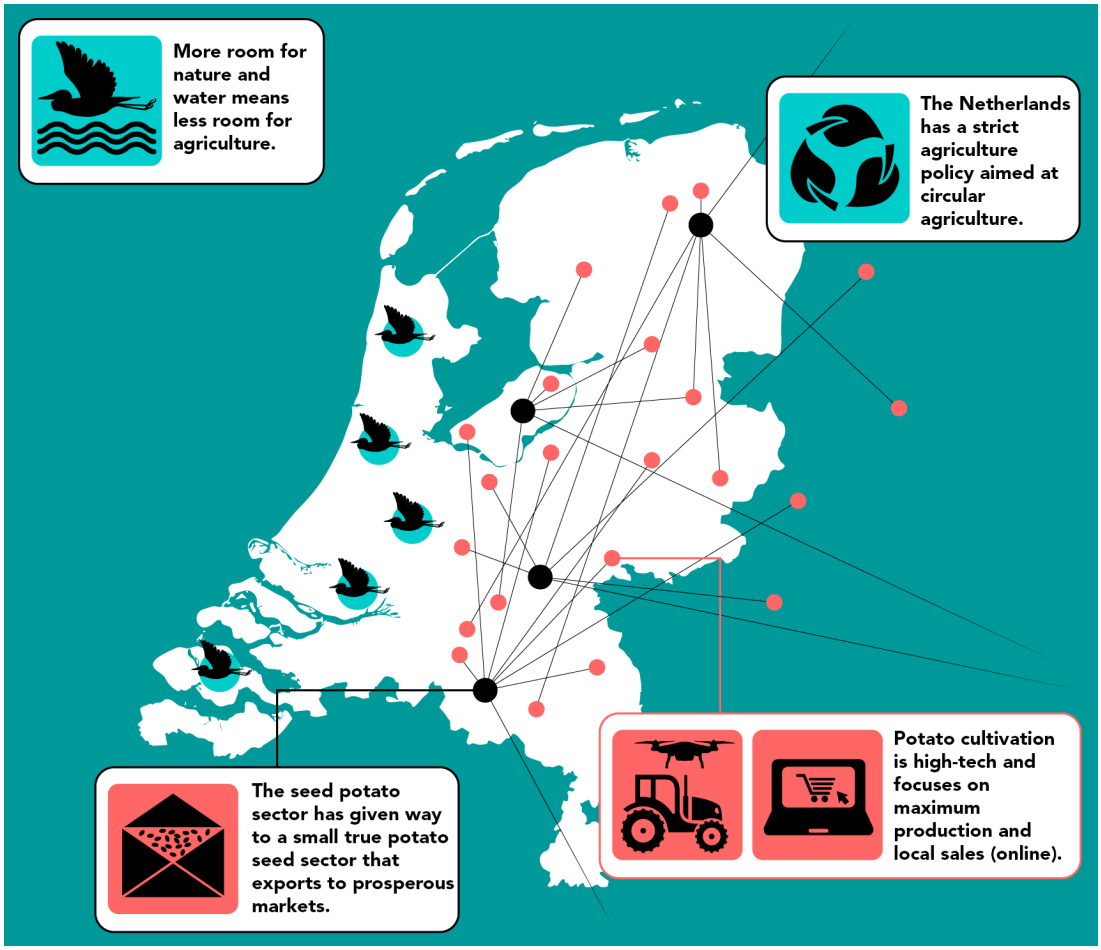
4.2 Scenario 2: Circular & High-Tech in 2040

In 2040, the Netherlands has been hit hard by global warming. A large proportion of Dutch agricultural land has had to make way for nature. This scenario makes use of the following four variable building blocks:

- **Control**: The Dutch government imposes strict ecological sustainability conditions on companies in order to make the economy circular. The traditional Dutch seed potato sector has disappeared.
- **Demand**: Dutch consumers pay more for tasty, healthy, and varied food. Dutch potato growers focus mainly on local markets.
- **Technology**: Dutch agriculture relies heavily on technological innovation in order to deal with problems caused by climate change. Poorer countries cannot keep up with these technological developments.

- **Focus**: More space for nature in the Netherlands means that potato growers need to produce as much as possible on the limited area of agricultural land available.

Figure 3 Visualisation of the “Circular & High-Tech in 2040” scenario



Climate change forces government to take strict measures

It is 2040. Despite global climate agreements in 2015, 2020 and 2024, global warming has continued. Since the late 2020s, the Netherlands has had to contend with major problems regarding high water levels and salinisation. Policies aimed at raising the water level of peat meadow areas so as to combat soil subsidence and CO_2 emissions have led to agriculture in the west of the Netherlands making way for nature and recreation. The result is limited availability and high cost of agricultural land.

The government is aiming for a circular economy. In 2026, the “Ex-externalities Act” came into force, meaning that companies themselves have to compensate for external damage to health and the environment, otherwise incurring high fines. The government and the General Inspection Service for Agricultural Seed and Seed Potatoes (*Nederlandse Algemene Keuringsdienst voor zaaizaad en pootgoed van landbouwgewassen*, NAK) can access company data so as to quantify environmental impacts.

Under these conditions cultivating potatoes is only profitable for companies that operate on a large scale. With the switch to using true potato seed and mini-tubers – thus making it possible to grow potatoes on a limited acreage – the traditional Dutch seed potato sector has completely disappeared. Breeders supply directly to farmers who grow potatoes for consumption.

Development of potato markets
Dutch potato growers focus mainly on their own market. Farmers’ cooperatives, together with food platforms such as *Goozon*, have innovated the old idea of a “meal kit” with great success. At factories in the middle of farming country, they process crops into measured, fresh, and nutritious ready-to-eat meals, which are then delivered to people’s homes by drones. Over twenty years, Dutch potato consumption has thus increased by approximately 50% to 120 kilos per person per year. Consumer convenience is excellent, but many smaller supermarkets have had to shut down. A significant part of the cost of sustainable production is charged on to the consumer, who pays substantially more for food than in 2020.

Dutch trading companies supply true potato seed for a large part of Europe, North Africa, and the Middle East, developing varieties specifically to meet consumer taste and local conditions in these areas.

Technology for a circular potato sector on limited acreage
Innovation in the potato sector has really taken off. Not only is there large-scale use of technology and ICT throughout the entire chain – from seed production to sales – but there has also been a veritable revolution in potato breeding. The emphasis in breeding is on disease resistance, higher yields, tolerance of wet conditions, and nutrient efficiency.

Breeding companies utilise various different strategies for developing potato varieties. Some develop potatoes that grow directly from seed, which is easy to transport. Others develop hybrid potatoes that still need one or two propagation steps but guarantee a higher yield. There is also a great deal of investment in genetic modification techniques such as CRISPR-2.0, with which the genetic material of the potato can be modified.

Companies are permitted under breeder’s rights legislation to utilise the genetic traits of competitors’ hybrid varieties.

Production of true seed and mini-tubers takes place under LED lamps in special production plants. The cultivation of starch - and ware potatoes takes place out in the open field using high-quality measurement -, control -, and management technologies so as to increase production and reduce costs. Sensors and data are utilised to optimise the use made of crop protection products. With disease-resistant potatoes and good resistance management, companies need to use only small quantities of chemicals for this purpose. In order to maintain a well-structured, nutrition-rich soil, growers apply strict rotation schedules with other crops. Pest control is achieved mainly by means of nanotechnological solutions, because the limited area available for agriculture does not provide space for laying out flowery field margins.

The use of high-tech farming methods is widely accepted by the public because it is seen as necessary to cope with climatic conditions.

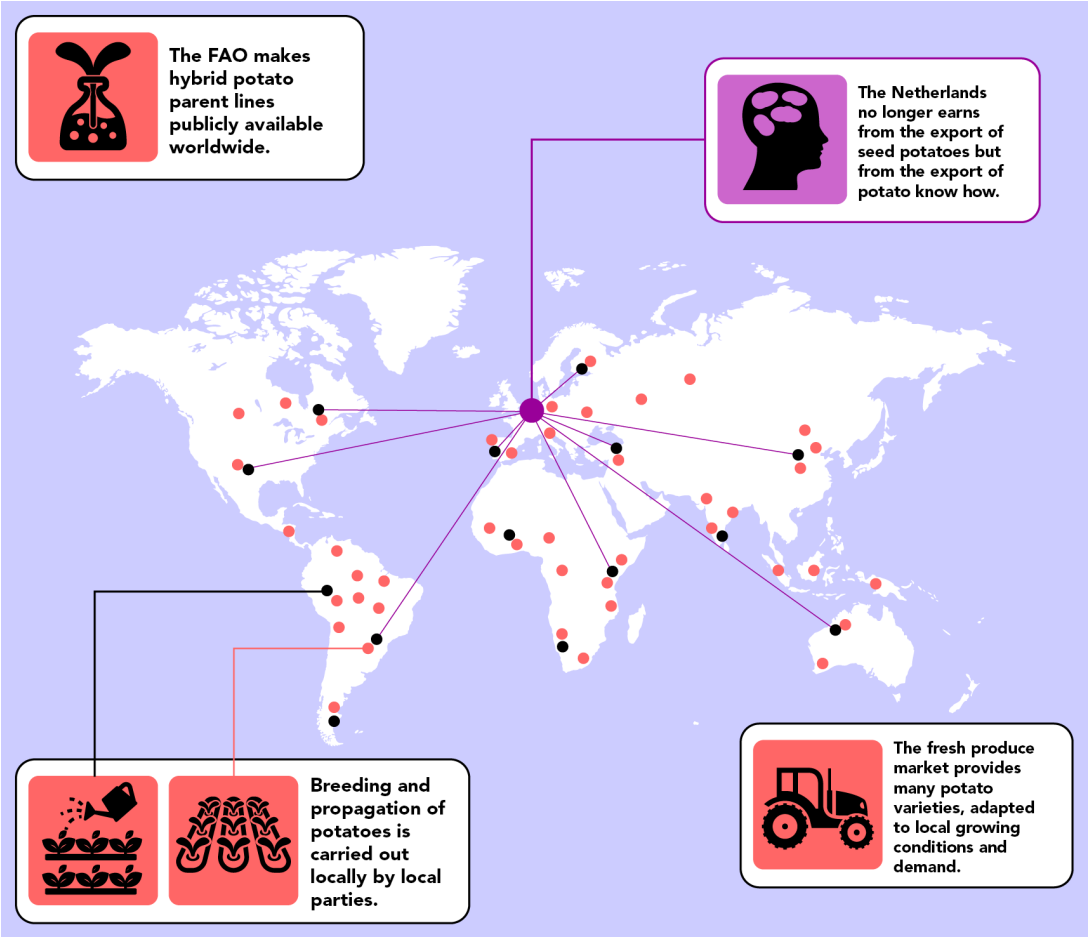
What about the rest of the world?
Together with a number of other European countries, China, the US and Canada, the Netherlands leads the way in the technologisation of agriculture. Because poor countries have been unable to invest in a sustainable agricultural system, the difference with them has grown in recent decades. The International Potato Centre (CIP) launched a number of pilot projects in the 2020s to promote the cultivation of hybrid potatoes in those countries, as true potato seed requires an intensive cultivation and irrigation system. Those projects did temporarily produce promising results, but after the departure of the CIP there was a rapid switch back to traditional cultivation methods. In a large part of the world the poor conditions of small farmers have therefore changed very little over the past 30 years.

4.3 Scenario 3: Diversified Markets in 2040

In 2040, patents on the natural properties of plants have been abolished worldwide. Public organisations ensure the accessibility of suitable potato parent lines. This scenario makes use of the following four variable building blocks:

- **Control**: Breeders worldwide utilise hybrid breeding to develop regionally adapted varieties. The Dutch seed potato sector produces only for the local market. The Netherlands trades worldwide in know-how about breeding and integrated potato production chains.
- **Demand**: Consumer interest in local food has increased, even though food has become more expensive. The processing industry demands uniform varieties.
- **Technology**: Innovation in the potato sector focuses mainly on the natural breeding of varieties.
- **Focus**: A large part of global production is on a small scale and diversified, utilising local infrastructures. Potatoes for the processing industry are produced in bulk by large farming companies.

Figure 4 Visualisation of the “Diversified Markets in 2040” scenario



Hybrid breeding widely available

It is 2040. Breeders all over the world are using hybrid breeding to develop varieties that are optimally adapted to local tastes and growing conditions. A few years after the European Union decided to no longer allow patents on the natural properties of plants, this decision was adopted by governments worldwide. It has led to a decline in companies’ interest in the use of genetic modification. Subsequently, national research institutes and international organisations such as the FAO and the Consultative Group for International Agricultural Research (CGIAR) have worked to develop a comprehensive range of potato parent lines and make them publicly available. With these parent lines as the basis, start-up companies and hobby growers are thus also able to develop hybrid varieties.

Breeding of varieties for consumption generally takes place close to market by local breeders. Competition on the world market for potato starting material is intense, with

specialised breeding companies each serving their own local market. Hybrid true potato seed is propagated in one or two steps into seed potatoes that can be grown by farmers for consumption. Various local infrastructures have developed around the breeding, propagation, and cultivation of potatoes.

A number of poor countries have not yet been successful in setting up local breeding companies. Countries such as Congo and Burundi import their true seed from elsewhere, but because this seed is not well adapted to regional conditions, crop yields are low. Small farmers in these areas also use part of their harvest as seed potatoes each year. If the disease resistance of their potatoes is disrupted, plant protection products are not always available. This has locally led to major problems.

Diversity but also uniformity

Potato consumption in countries such as China and India has continued to grow, with total production increasing by almost a quarter over 20 years to 480 million tonnes. Globally, two types of market are developing. On the one hand, there is a local fresh produce market supplied by small-scale farmers and, on the other, a market for bulk varieties from the processing industry, supplied by large-acreage farms.

The fresh produce market for potatoes is highly diverse worldwide. Because new varieties can be developed faster, even small breeders are willing to experiment with potatoes. In the Netherlands, there are new varieties in the supermarket each year, and consumers have completely rediscovered fresh, unpeeled potatoes. Potatoes are viewed increasingly as a vegetable rather than as a source of carbohydrates, because their nutritional value and vitamin content is so high.

In the processing industry the picture is entirely different: a limited range of varieties suffices for processors because they are assured of a good crop thanks to the robustness of the potatoes involved. The parent lines of these varieties are continuously genetically updated by company breeders to make them resistant to newly emerging diseases; this is an advantage that hybrid breeding has over conventional breeding. The McFries French fries factory recently started production of the new Russet Burbank 5.7 and Clearwater Russet 11 varieties. The organic hybrid potato Agriana 5000 is popular among Dutch processors. Farmers barely notice this succession of similar varieties, and processors hardly need to adjust the settings of the machines in their factories.

Open potato science

Breeding research for publically available parent lines is carried out in the laboratories of national and international research centres. In addition, international calls for tenders are issued each year to which private breeders can respond. A great deal of knowledge

is now available about the genetic background of the potato, and scientists have developed a whole range of affordable genetic markers.

The Dutch potato sector has changed radically

Due to local breeding of potato varieties worldwide, demand for Dutch potato seed has fallen sharply. Only a small number of specialised companies in the Netherlands still produce true seed and seed potatoes, all destined for the domestic market. At the beginning of the 21st century, potato cultivation was the cornerstone of Dutch arable farming. Little is left of that, and many farmers have been hit hard by the change. Furious about these developments, hundreds of farmers once again demonstrated outside the Dutch Parliament in 2024 and 2026. Many have had to sell their farm.

The Netherlands has acquired a new role as an exporter of know-how about potato production chains. In countries such as China and India, the ability to breed local varieties, close to the market, has by itself turned out to be insufficient to ensure good yields. Selling know-how of integrated production chains to those countries has become a profitable business model. There has therefore been an enormous increase in the number of “potato consultants” in the Netherlands. These people have specific knowledge of a particular area and work closely with local parties in developing a local production chain.

5 Scenario-transcending lessons

The three scenarios offer three visions of a possible future. In this section, we look in greater detail at the desirable and undesirable aspects of these visions (5.1) and the conditions under which the desirable aspects can be reinforced and the undesirable ones mitigated (5.2). Based on these conditions, we then draw scenario-transcending lessons for the socially responsible use of technological innovation in hybrid potato breeding.

These lessons derive from the results of the two workshops, the supplementary discussions, and a meeting with the Potarei valorisation panel. The lessons offer companies, civil-society organisations, and the government a basis for steering the technological innovation of hybrid potato breeding in the desired direction, i.e. so as to contribute to ecological sustainability and food security and to a promising business model for the Dutch potato sector.

5.1 Comparing the three scenarios

5.1.1 Scenario 1: Global Duopoly in 2040

In the Global Duopoly scenario, a large-scale concentration of companies is accompanied by a strong focus on bulk production and cost savings. In addition to potato seed, these companies provide farmers with the necessary technical infrastructure, in which much use is made of crop protection products. This increases global potato production, thereby contributing to food security. However, the limited willingness of the companies to invest in innovation, combined with the protection of new potato parent lines with patents, is at the cost of their ability to develop new varieties. Within this scenario, the Dutch seed potato sector has declined in importance. The sector now produces only for the European market.

This scenario is in line with the current dominant trend in agriculture towards increasing scale, intensification, and company mergers. Many of the involved stakeholders see this scenario as “business as usual”. The substantial contribution that the two companies make to world food security is viewed as a positive and desirable development. But those involved also note that addressing the world food issue is not only a matter of increasing yields but also of the distribution, transportation, and trade

of food, aided by open borders and national distribution networks. Moreover, criticisms can be made of the lack of attention within this scenario to soil fertility, crop diversity, and biodiversity. A one-sided focus on scaling up, intensification, and the use of chemical crop protection products can ultimately be at the expense of agricultural yields.

Although this first scenario is most in line with the current dominant focus on scaling up and increasing yield, those involved all expect that such a large-scale concentration of a few mega-companies will not in fact come about. Because of the mentioned points of criticism, such developments are expected to run up against biological boundaries at an earlier stage, evoking opposing social and geopolitical forces that call for more sustainable production. Such critical voices can already be heard on a regular basis in 2020.

5.1.2 Scenario 2: Circular & High-Tech in 2040

In the Circular & High-Tech scenario, high-tech resources are used to deal with environmental problems while maintaining a high yield. Urgent problems caused by climate change demand sustainable production. This goes hand in hand with broad public acceptance of high-tech, intensive agriculture, including the use of genetic modification. The switch to the use of true potato seed instead of tubers means the end of the Dutch seed potato sector. In this scenario, the use of high-tech agricultural methods is reserved for more prosperous, mainly Western, countries.

This scenario fits in with another important social trend, namely sustainability. The scenario is a clear example of “land sparing”, with a techno-optimistic approach. The scenario draws inspiration from the ecomodernist vision of sustainability. This too is open to criticism, for example as regards the extent to which consumers will be willing to pay substantially higher prices for more sustainable products.

Various parties also question the level of sustainability of this scenario. Although the use of high-tech farming methods can make food production less polluting, it also leads to underutilisation of all kinds of natural processes. In this vision, a more resilient agricultural system would benefit from greater structural attention to soil fertility, crop diversity, and biodiversity. That requires paying more attention to the complex relationship between the cultivation of crops and the natural environment: nutrients that the crops extract from the soil, vegetation in the immediate vicinity, and the insect life that thrives in it. The use of natural pest control methods is appropriate in this context, for example.

The lack of attention paid to the issue of global food supply is also a defect of this scenario. In the long run, this scenario could lead to increasing tensions in North-South relations.

5.1.3 Scenario 3: Diversified Markets in 2040

The Diversified Markets scenario involves less high-tech agriculture. Public access to high-quality parent lines makes local production of potato seed and seed potatoes possible in many parts of the world, close to the consumer. As a result, a great deal of seed potato production has been relocated from the Netherlands to other countries. Breeders worldwide are working on a wide variety of potato varieties for the fresh produce market. At the same time, the processing industry uses only a limited number of risk-free varieties, which are produced in bulk. The Netherlands earns money from its knowledge advantage in the field of potato cultivation and the cooperation between various links in the potato production chain (chain integration).

The future vision outlined in this third scenario is the result of the abolition of patents and the emergence of participatory breeding, in which breeders work together with growers to select varieties adapted to local conditions. This scenario offers scope for global diversity, with locally adapted varieties contributing to food security.

It mainly raises questions among workshop participants as to the feasibility of making potato parent lines publicly available. Public availability of parent lines makes it economically less attractive for breeders to invest in the development of new varieties, which can have a negative impact as regards the necessary innovation. The advent of participatory breeding is also viewed as unrealistic in light of the current dominant positions within the potato sector. Moreover, it is questionable whether the Netherlands can maintain a strong knowledge position if the production of seed potatoes has been largely relocated abroad.

5.2 A viable future for potatoes

The scenarios show that societal forces influence the way in which a technological innovation such as hybrid potato breeding takes shape. Conversely, the technology also affects relations within the sector. Understanding the interaction between the two offers pointers for guiding this innovation in the right direction.

Our analysis of the results of the scenario workshops and the supplementary discussions has produced three scenario-transcending lessons for the socially

responsible use of hybrid potato breeding that contributes to ecological sustainability, global food security and a promising business model for the Dutch potato sector. These lessons are elucidated in the following sections. Points to be considered are:

- an innovative market for breeders;
- aiming for new varieties that contribute to ecological sustainability and food security;
- maintaining the knowledge position of the Dutch potato sector.

5.2.1 An innovative market for breeders

It is highly important to continue to pursue development of new potato varieties that contribute to food security in an ecologically sustainable manner. The various scenarios show that development of innovative potato varieties is associated to a significant extent with how the breeding market is organised.

Large multinational companies are expected to be insufficiently willing to invest in the development of genetic traits that make possible long-term resistance to diseases. Their business model is based on adapting the cultivation system that is used to the available potato variety, not on the innovation of varieties. The patenting of innovations may also be at the expense of the accessibility of these genetic sources for other parties. In this scenario, innovative start-ups have little chance of success because the multinationals control the entire chain and have easier access to breeding know-how and genetic resources. This situation is outlined in the first scenario, Global Duopoly.

The third scenario, Diversified Markets, also raises the question of how innovation can remain attractive for potato breeders. The potato parent lines are described by those involved in this research as the “crown jewels” of the hybrid breeder. If parent lines are made publicly available and numerous parties can breed with them, it becomes less worthwhile for breeders to invest in developing parent lines. This could act as a barrier to the necessary innovation.

Lesson 1: Legislation and regulations for the development of new varieties
It is important to maintain an innovative market for breeders so that new potato varieties that contribute to food security in a sustainable manner continue to be developed. Governments must guarantee, through national and international legislation and regulations, that:

- breeders retain access to genetic material and new knowledge;
- breeders can make use of a variety of breeding techniques; and

- new potato varieties on the market are subject to protection, so that it is worthwhile for breeders to invest in them.

Governments can ensure this by:
- establishing and maintaining gene banks;
- continuing to fund public knowledge institutions so that a common knowledge base is maintained; and
- retain provisions such as plant breeders' rights that allows breeders to protect and monetize on new varieties.

5.2.2 Ecologically sustainable varieties that contribute to food security

An important potential benefit of hybrid breeding is the rapid development of ecologically sustainable potato varieties that contribute to food security. This is implemented differently, however, in each scenario.

For example, hybrid breeding in Scenario 2, Circular & High-Tech, is utilised so as respond rapidly to new variants of pathogens by crossing new resistance genes into existing varieties. In this way, growers, processors, and consumers do not need to repeatedly get used to a new variety. However, the downside of breeding for specific traits within the existing types of varieties is that varieties remain very similar to one another, at the expense of genetic diversity. This is detrimental to biodiversity and soil fertility.

In Scenario 1, Global Duopoly, potatoes are bred that can be grown on a large scale. Also in Scenario 3, Diversified Markets, there is large-scale cultivation of potatoes for the processing industry. For the fresh produce market, breeders specifically develop potatoes – based on available potato parent lines with built-in disease resistance – that are adapted to local conditions. Both types of potatoes are labelled "robust", but in the context of different types of agriculture: for the organic sector a potato is "robust" when it has crossed-in disease resistance, while in the conventional sector "robust" means that the potato can be grown within a large area. These varieties contribute to farmers' yield certainty, but in a much more intensive type of agriculture than in the organic sector. The question is whether large-scale agriculture is sustainable in the longer term and – by extension – whether it promotes food security.

Lesson 2: Ensure diversity of genes, varieties, and also cultivation systems
The different ways in which hybrid breeding is used in the various scenarios show that breeding technology alone does not offer a solution to issues of sustainability and food

security. The technology offers opportunities both for ensuring broad genetic diversity and for developing varieties that are virtually identical but which often differ in terms of the type of resistance genes that have been incorporated. The technology can thus be utilised in various different breeding strategies and cultivation systems. It is important to promote a diversified approach. In order to ensure societal embedding, careful consideration must also be given to the *combination* of variety, cultivation system, and production chain. In the view of the parties involved, the government is the appropriate party to set conditions so that hybrid potato breeding actually helps to tackle the various challenges facing society.

It is important that disease resistances are built in sustainably. That process begins with the development of new varieties with, for example, an accumulation of resistance genes ("stacking"), which prevents diseases from quickly breaking down the plant's resistance. In Scenario 3, Diversified Markets, public institutions ensure that potato parent lines meet these conditions. Companies can also be (made) responsible for "stacked resistance" and offer transparency about which resistance genes are utilised.

Hybrid breeding can contribute to the usage of cultivar mixtures in the field. As a result, a disease can spread less rapidly, reducing the likelihood that the entire harvest will fail if it does manage to do so. If potato varieties are developed that differ only in terms of crossed-in resistance genes, the varieties should be easier to grow and process. Hybrid breeding can thus reduce the risk of harvest loss due to disease in the case of bulk production.

Varieties that are broadly applicable and niche varieties can be grown side by side. It is precisely a diversified approach that offers opportunities for food security in both the short term – by contributing to yield certainty – and the long term, by ensuring broad genetic diversity.

5.2.3 Knowledge as a business model

Because technological innovation in agriculture presupposes an active role on the part of the business community, the Dutch potato sector's business model is an important focus in this study.

The Netherlands is the world's biggest exporter of certified seed potatoes, but only a small proportion of the seed potatoes used worldwide are certified. In many countries, potato yields are suboptimal, partly due to a lack of good quality potato varieties. Hybrid breeding offers an opportunity to improve that situation. Sustainable varieties propagated from true potato seed can reach areas that do not currently have access to

clean seed potatoes. This is good for food security in those areas, and it also offers the Dutch potato sector the opportunity to expand its export market. There is therefore a great deal to be gained as regards improved potato cultivation.

However, hybrid breeding can also have a negative impact on the Dutch potato sector. In all three scenarios that sector undergoes major changes. A complete transition to hybrid potatoes grown from seed instead of from seed potatoes seems remote, given the leading position of the sector at present. The scenarios show, however, that a leading position is not a matter of course, and that account needs to be taken of possible shifts in the global potato production chain.

Scenario 3, Diverse Markets, presents a different possibility for a promising business model for the Dutch potato sector. In this scenario, the sector earns money from exporting knowledge. The Netherlands is not only at the forefront in terms of R&D knowledge but also in terms of the know-how needed to structure an effective potato production chain, “from farm to fork”. It is questionable, however, whether exporting only chain-related knowledge, without maintaining an innovative home market for potatoes from which one can learn, is a sustainable business model in the long run.

Lesson 3: Invest in the know-how position of the Dutch potato sector
In order to continue to play a significant international role, it is important for the Dutch potato sector and the Dutch government to continue to invest in the development of both basic and applied knowledge. That applies both to knowledge of potato cultivation and the organisation of potato production within value chains.

The Dutch potato sector can profit from the production of potatoes in other countries by acquiring a pivotal position within local production chains. It is important that the new potato varieties are fully integrated into the local agricultural system. This requires investment in the further development of local potato infrastructures so as to optimise crops, but also specific know-how about local production conditions. The development of locally adapted varieties also requires close cooperation with farmers who can select varieties in their fields. In this regard, the sector can learn from Dutch vegetable breeding companies that operate internationally. These keep control of matters by performing the (preliminary) R&D for varieties in the Netherlands, while conducting more locally focused breeding work in local branches abroad, in coordination with local markets.

Commercial activities can thus go hand in hand with the pursuit of food security. The Dutch sector can also maintain its lead in the field of chain-related knowledge more effectively if it succeeds in acquiring a pivotal position within foreign potato production chains.

6 Conclusions

Based on this scenario study, the results of a study of the literature, and discussions with experts, we arrive at the following conclusions. These offer government, the business community, and civil-society organisations a basis for steering the technological innovation of hybrid potato breeding in a socially desirable direction.

Potatoes as a Dutch trump card
Dutch agriculture is facing major societal challenges: it is striving for more sustainable food production and wishes to contribute to global food security. Potatoes can play an important role in this: they are a crop with high nutritional value and are one of the world's most widely cultivated food crops. Because of its position as the biggest exporter of seed potatoes in the world and because of its leading knowledge position, the Dutch potato sector can lead the way in tackling these challenges.

A great deal to be gained
A great deal of progress can still be made worldwide as regards potato cultivation. Potato cultivation often has a high environmental impact. In a large part of the world it also produces low yields, partly due to the poor quality of the seed potatoes used. Hybrid potato breeding offers opportunities for increasing potato production in a sustainable manner. As a breeding technology it promises to bring new varieties onto the market more quickly that are resistant to potato blight or drought. It also makes growing potatoes possible from true seed, which is less susceptible to diseases and easier to transport. Furthermore, hybrid potatoes are an alternative to socially controversial techniques involving genetic modification, which in the EU must undergo a rigorous approval procedure with regard to health and safety.

Societal embedding
Technology alone is never the solution to societal challenges. If hybrid potato breeding is really to contribute to more sustainable cultivation and global food security, then it needs to be embedded within society. Only if certain economic and policy-related conditions are met can hybrid potatoes be expected to fulfil their promises. This also means making clear choices as regards the use of hybrid potato breeding.

Open innovation system
In order to tackle the challenges facing society, it is important to continually develop new potato varieties that are, for example, adapted to changing agricultural or climatic conditions. This requires an open innovation system, in which public facilities must ensure that breeders retain access to genetic material and new knowledge. This study

makes clear that the formation of monopolies within which large companies shield their innovations with patents is undesirable. A provision such as plant breeders' rights should be maintained so that it is worthwhile for breeders to invest in developing new varieties.

Sustainable varieties that contribute to food security
Government regulation should aim to ensure a breeding sector that contributes to the development of varieties for use in both large-scale and small-scale agriculture, with resistance genes being incorporated in a sustainable manner. Greater concern for the environment, nature, and the future of the world food supply cannot be left to the market alone. If government makes ecological sustainability and food security the leading factor, new market opportunities will arise. This can be accomplished within various different scenarios and is in line with the Netherlands' mission-oriented innovation policy and global agreements on the Sustainable Development Goals (SDGs).

Maintaining the leading position requires investment in knowledge development
The leading position of the Dutch potato sector is not self-evident. Successful introduction of hybrid potatoes may lead to the demise of the country's seed potato sector. However, the sector's strong knowledge position can form the basis for a new business model in the form of the export of know-how regarding potato cultivation and the potato production chain. The vast majority of the world's potato cultivation takes place under sub-optimal conditions. Disease-free seed and up-to-date knowledge can improve those conditions. In order to maintain the Netherlands' leading position in potato cultivation and the ability to continue to innovate, continued investment in public knowledge development and R&D is required.

Action required from all three
By no means is it a foregone conclusion that the promises of the hybrid potato can actually be fulfilled. Technological innovations such hybrid potato breeding do not follow only a single possible path of development. A contribution of this technology to an ecologically sustainable and secure food supply requires it to be integrated into agricultural practice, as well as creating suitable conditions that make a contribution possible. How such innovation takes shape in actual practice is determined by the economic, social, and policy decisions that are adopted. Companies can choose – within certain margins – how sustainably they wish to operate and what contribution they wish to make as regards the world food issue. These choices are partly driven by the applicable regulations and by government policy regarding knowledge and innovation, as well as by the public pressure that civil-society organisations exert on companies. This means that companies, civil-society organisations, and the government all need to take action.

Bibliography

ABN AMRO (2010). Akkerbouw, trends en toekomst. Consulted on 4 December 2019: www.abnamro.nl/nl/images/Generiek/PDFs/020_Zakelijk/02_Sectoren/Agrarisch/Akkerbouw%252C_trends_en_toekomst.pdf

AGF (2018). Aardappel wint aan populariteit in Azië en Afrika. Consulted on 4 December 2019 op www.agf.nl/artikel/173101/Aardappel-wint-aan-populariteit-in-Azie-en-Afrika

Almekinders, C. J. M., Mertens, L.; Loon, J.P. van; Lammerts Van Bueren, E. (2014). "Potato breeding in the Netherlands: a successful participatory model with collaboration between farmers and commercial breeders." Food Security: 515-524.

Asselt, M. van, F. van der Molen, A. Faas and S. Veenman (2010). Uit zicht: toekomstverkennen met beleid, Amsterdam University Press.

Bakker, E. de, Bokma-Bakker, M., Bogaardt, M. J., Woelders, H., Minten, S., Leenstra, F., & Beekman, V. (2011). Maatschappelijke acceptatie van nieuwe technologie in de landbouw. LEI part of Wageningen University & Research.

Bejo (2019). Bejo introduces its first true potato seed variety. Consulted on 4 December 2019 at www.bejo.nl/magazine/bejo-introduceert-haar-eerste-true-potato-seed-ras

CBS (2018). Landbouw gebruikt 5,7 miljoen kg chemische middelen. Consulted on 4 December 2019 at www.cbs.nl/nl-nl/nieuws/2018/30/landbouw-gebruikt-5-7-miljoen-kg-chemische-middelen

Bennett, E. M. (2017). "Changing the agriculture and environment conversation." Nature Ecology and Evolution 1: 1-2.

Benschop, H. P. & Veenma, K. (2012). "Toekomstverkenningen in het beleidsonderzoek." Beleidsonderzoek Online 10.

Beumer, Koen & Edelenbosch, R. (2019). "Hybrid potato breeding: A framework for mapping contested socio-technical futures." Futures 109: 227-239.

Bonny, S. (2017). “Corporate Concentration and Technological Change in the Global Seed Industry.” Sustainability 9(9): 1632.

Boersma, H. (2018). “Keer de natuur de rug toe om haar te redden.” Podium voor Bio-ethiek 28.4: 6-8.

Boom, N. van der (2019). Bas Alblas: “Fritesoorlog baart ons zorgen”. Boerenbusiness. Consulted on 4 December 2019 at www.boerenbusiness.nl/akkerbouw/artikel/10881117/bas-alblas-039-fritesoorlog-baart-ons-zorgen-039

Bronson, K. (2015). “Responsible to whom? Seed innovations and the corporatization of agriculture.” Journal of Responsible Innovation 2: 62-77.

Ceccarelli, S., Guimarães, E. P. & Weltzien, E., eds. (2009). “Plant breeding and farmer participation.” Plant Breeding: 671.

Dammers, E., S. van “t Klooster, B. de Wit, H. Hilderink, A. Petersen & W. Tuinstra (2013). “Scenario’s maken voor milieu, natuur en ruimte: een handreiking.”

Duijne, F. van & Bischop, P. (2018). Introduction to Strategic Foresight.

Duijne, F. van & Klooster, S. van “t (2019). Toekomstverkenning en scenario’s bij de Omgevingsvisie Zaanstad. Consulted on 14/1/2020 at www.futuremotions.nl/gratis-download-e-book

Engwerda, J. (2015). Sector profiteert niet van DuRPh-project. Boerderij. Consulted on 4 December 2019 at www.boerderij.nl/Akkerbouw/Nieuws/2015/9/Sector-profiteert-niet-van-DuRPh-project-2682593W

Engwerda, J. (2019). “Sneller betere rassen met hybride diploïde aardappelen” Boerderij. Consulted on 4 December 2019 at www.boerderij.nl/Akkerbouw/Achtergrond/2019/2/Sneller-betere-rassen-met-hybride-diploide-aardappelen-388943E

FAO (2017). Statistics World Potato Production. Consulted on 1 September 2019 at www.fao.org/faostat/en.

FAO (2017). The Future of Food and Agriculture. Trends and Challenges, FAO Rome.

Grinsven, H. v., M. van Eerdt & H. Westhoek (2014). “Landbouw en voedsel.” Balans van de Leefomgeving. The Hague: PBL.

Habets, M., Hove, L. van & R. van Est (2019). Genome editing bij planten en gewassen – Naar een modern biotechnologiebeleid met oog voor verschil in risico’s en bredere afwegingen. The Hague: Rathenau Instituut.

Imarc Group (2019). Frozen Finger Chips (Frozen French Fries) Market: Global Industry Trends, Share, Size, Growth, Opportunity and Forecast 2019-2024. Consulted on 1 September 2019 at www.researchandmarkets.com/research/svqjn3/20_bn_frozen?w=12

Janssens, S. R. M., et al. (2006). Visie op de aardappelkolom, Wageningen.

Lammerts van Bueren, E. T. & J. P. van Loon (2011). De praktijk van kleine kwekers in de aardappelveredeling in Nederland.

Levidow, L. (2015). “European transitions towards a corporate-environmental food regime: Agroecological incorporation or contestation?” Journal of Rural Studies 40: 76-89.

Lindhout, P., Meijer, D., Schotte, T., Hutten, R. C., Visser, R. G., & van Eck, H. J. (2011). Towards F 1 hybrid seed potato breeding. Potato Research, 54(4), 301-312.

Liu, Z., M. A. Jongsma, C. Huang, J. H. Dons & S. O. Omta (2015). “The sectoral innovation system of the Dutch vegetable breeding industry.” NJAS-Wageningen Journal of Life Sciences 74: 27-39.

Louwaars, N., et al. (2009). Veredelde zaken: de toekomst van de plantenveredeling in het licht van de ontwikkelingen in het octrooirecht en het kwekersrecht. Wageningen: CGN.

Mampuys, R., & Stemerding, D. (2010). Mondiale Motivatie of Europese Eigenheid? Vier scenario’s voor ggo’s in de Europese Landbouw. Rathenau/ COGEM.

NAO (2019). Pootgoedexport in tonnen oogst. Consulted on 4 December 2019 at www.nao.nl/nl/markt/exportcijfers.

Nekkers, J. (2009). Wijzer in de toekomst: werken met toekomstscenario’s, Business Contact.

NOS (2016). Het Noorden wil Silicon Valley van de aardappel worden. Consulted on 4 December 2019 at https://nos.nl/artikel/2140949-het-noorden-wil-silicon-valley-van-de-aardappel-worden.html.

Potato Business (2018). Global frozen fries market reaches USD19bn. Consulted on 4/08/18 at www.potatobusiness.com/business2/1873-global-frozen-fries-market-reaches-usd19bn

Rijswick, C. van (2016). Word geen ‘couch potato’: trends in de internationale aardappelketen. Rabobank presentatie bijeenkomst Pootgoedacademie 2016. Consulted on 4 December 2019 at http://pootaardappelacademie.nl/system/files/documenten/nieuws/paa_emmeloord_rabobank.pdf

Ruyter, J. van (2016). In de ban van de Pieper: Aardappelteelt dreigt uit Nederland te verdwijnen zonder Europees level playing field. ABN Amro. Consulted on 4 December 2019 at https://insights.abnamro.nl/2016/10/in-de-ban-van-de-pieper

Stilgoe, J., R. Owen & P. Macnaghten (2013). “Developing a framework for responsible innovation.” Research Policy 42(9): 1568-1580.

Thomas-Sharma, S., et al. (2015). “Seed degeneration in potato: The need for an integrated seed health strategy to mitigate the problem in developing countries.” Plant Pathology: 1-14.

Verbeek, J. (2017). Miljoenen voor Wageningse ontwikkelaar van aardappelzaad. Financieel Dagblad: 28-11-17.

Vriend, H. d. & E. T. Lammerts van Bueren (2014). Aardappelveredeling: oude eigenheimers in de Puree? De kracht van Platformen: nieuwe strategieën voor innoveren in een digitaliserende wereld. In: M. Kreijveld, J. Van Deuten & R. Van Est, Vakmedianet Management B.V: 218-259.

Wilde, S. de (2015). Van autonome robots tot zilte aardappels. The Hague: STT. Consulted on 4 December 2019 at http://edepot.wur.nl/355019.

WUR (2015). Resistentie-genen van wilde verwanten van gewassen bieden wereldwijd kansen voor duurzamere landbouw. Consulted on 15-7-2017 at www.wur.nl/nl/nieuws/Resistentiegenen-van-wilde-verwanten-van-gewassen-bieden-wereldwijd-kansen-voor-duurzamere-landbouw-.htm.

Appendix 1: The Potarei Project Team

The research team for the NWO's Potarei Socially Responsible Innovation programme comprises the following persons:

Wageningen University & Research
- Paul Struik (project coordinator)
- Luuk van Dijk
- Conny Almekinders

University of Groningen
- Sjaak Swart
- Koen Beumer

Rathenau Instituut
- Rosanne Edelenbosch
- Geert Munnichs
- Dirk Stemerding

Solynta
- Pim Lindhout
- Michiel de Vries

Appendix 2: Guidance committees

Valorisation panel
The results of the Potarei study were discussed twice a year with the members of the Valorisation panel, consisting of the following representatives of the parties involved:

- Niels Louwaars, Plantum
- Dick Hylkema, Dutch Potato Organisation
- Guus Heselmans, Meijer Potato
- Leo van Marion, McCain Foods Europe
- Sijas Akkerman, Noord Holland Nature and Environment Federation
- Dick Jung, Ministry of Infrastructure and Water Management
- Marien Valstar, Ministry of Agriculture, Nature and Food Quality
- John van Ruiten, National General Inspection Service for Horticulture
- Anton Haverkort & Corné Kempenaar, Wageningen University & Research
- Evert Jacobsen, Wageningen University and Research
- Edith Lammerts van Bueren & Peter Keijzer, Louis Bolk Institute
- Bram de Jonge, Oxfam Novib

Scenarios guidance committee
When drawing up the potato scenarios, we were advised by the following foresight experts:

- Marjolein van Asselt, Maastricht University
- Freija van Duijne, Future Motion
- PJ Beers, DRIFT
- Ed Dammers, PBL Netherlands Environmental Assessment Agency

Appendix 3: Sources consulted

Parties involved

The following people contributed to this study through interviews, scenario workshops, and discussions after the scenario workshops:

- Sjefke Allefs, Agrico
- Conny Almekinders, Wageningen University & Research, Social Sciences
- Gé Bentvelsen, ABZ Seeds
- Kees van Beek, Biotrio
- Herman van Bekkem, Greenpeace
- Gert van der Bijl, Solidaridad
- Hilko Bos, Maatschap Bos
- Koos Bos, Maatschap Bos
- Chissa Bruijs, Netherlands General Inspection Service
- Erika den Daas, Meijer Potato
- Luuk van Dijk, Wageningen University & Research
- Berend-Jan Dobma, Dr. R.J. Mansholt's Veredelingsbedrijf
- Jacob Eising, Den Hartigh
- Boelie Elzen, Wageningen University & Research
- Henk van de Haar, Netherlands General Inspection Service
- Anton Haverkort, Wageningen University & Research
- Guus Heselmans, Meijer Potato
- Roel Hoekstra, Centre for Genetic Resources the Netherlands
- Jan Willem Hoopman, Hoopman group
- Evert Jacobsen, Wageningen University & Research
- Edith Lammerts van Bueren, Louis Bolk Institute
- Pim Lindhout, Solynta
- Niels Louwaars, Plantum
- Jan van Loon, TPC
- Peter Kooman, Aeres University of Applied Sciences
- Jan Karel Kwisthout, Ministry of Infrastructure and Water Management
- Leo van Marion, McCain
- Leon Mol, Ahold
- Maaike Raaijmakers, Bionext
- Hans Renia, Nsure
- Carl Rentes, Solynta
- Judith de Roos, Plantum
- John van Ruiten, Netherlands General Inspection Service for Horticulture

- Albert Schirring, Bayer
- Paul Struik, Wageningen University & Research
- Marien Valstar, Ministry of Agriculture, Nature and Food Quality
- Cor van der Weele, Wageningen University & Research
- Karst Weening, Dutch Potato Association

Literature

The following reports, scenario studies, and manifests inspired the driving forces and trends behind the scenarios:

- Asafu-Adjaye, J. et al. (2015). An Ecomodernist Manifesto. Most recently consulted on 11 December 2019 at www.ecomodernism.org/manifesto-english/
- Bakkes, J. A., Laura, A., Oonsie, B., Hoff, H., & Garry, P. (2009). Getting into the right lane for 2050: a primer for EU debate. Bilthoven: PBL Netherlands Environmental Assessment Agency.
- Boersma (2015). Ecomodernisme voor beginners – een spoedcursus in een stroming die de groene beweging wil vernieuwen. De Correspondent, 19 November 2015.
- CPB/PBL (2015). Toekomstverkenning Welvaart en Leefomgeving. Nederland in 2030 en 2050: twee referentiescenario's. The Hague: PBL Netherlands Environmental Assessment Agency/Centraal Planbureau., Most recently consulted on 11 December 2019 at www.cpb.nl/publicatie/toekomstverkenning-welvaart-en-leefomgeving-wlo-2015
- Du Cann, C. (2012). The Dark Mountain Project: In search of a new narrative. Most recently consulted on 11 December 2019 op www.resilience.org/stories/2012-08-28/dark-mountain-project-search-new-narrative/ http://dark-mountain.net/about/manifesto
- Faasse, P., van der Meulen, B., & Heerekop, P. (2014). Vizier Vooruit: Vier Toekomstscenario's voor Nederlandse Universiteiten. The Hague: Rathenau Instituut.
- Food and Agricultural Organization of the United Nations (2017). The Future of Food and Agriculture: trends and Challenges. Rome: FAO.
- IPES-Food (2016). International Panel of Experts on Sustainable Food Systems, From Uniformity to Diversity: A Paradigm Shift from Industrial Agriculture to Diversified Agroecological Systems, IPES-Food.
- Klein, N. (2015). The Leap Manifesto: a call for caring for the earth and one another. Most recently consulted on 11 December 2019 at www.resilience.org/stories/2015-09-16/the-leap-manifesto-a-call-for-caring-for-the-earth-and-one-another

- Mampuys, R., & Stemerding, D. (2010). Mondiale Motivatie of Europese Eigenheid? Vier scenario's voor ggo's in de Europese Landbouw. Rathenau/ COGEM.
- Öborn, I., Vrede, K., Bengtsson J. & Magnusson, U. (2012). "What challenges is agriculture facing? Five scenarios for 2050." The Futures of Agriculture, 40.
- Onbekend (2014). Beyond Sustainability: A Manifesto. Planet 3.0. Most recently consulted on 11 December 2019 at http://planet3.org/beyond-sustainability-a-manifesto
- Onbekend (2014). Solarpunk. No Tech Magazine. Most recently consulted on 11 December 2019 at www.notechmagazine.com/2015/11/solar-punk.html
- Onbekend (2015). Degrowth Manifesto. Most recently consulted on 11 December 2019 via https://wiki.p2pfoundation.net/Degrowth_Manifesto
- Poppe, K. & de Wilde, S. (2016). Next Farming: de landelijke leefomgeving van morgen. Most recently consulted on 11 December 2019 at https://wijmakennederland.nl/bijdrage/longread/?flush=true.
- Rabobank (2011). In 2030: vier toekomstscenario's voor bedrijven. Most recently consulted on 11 December 2019 at www.google.com/url?sa=t&rct=j&q=&esrc=s&source=web&cd=1&ved=2ahUKEwip6Mq80qDlAhVRMewKHbuFDDoQFjAAegQIBhAC&url=https%3A%2F%2Feconomie.rabobank.com%2Fpublicaties%2F2010%2Fdecember%2Fscenariostudie-in2030-4-toekomstscenarios%2F&usg=AOvVaw33VEuCE83-KCFGg5bD8LfZ
- Scheerder, J., Hoogerwerf, R., & de Wilde, S. (2014). Horizon Scan 2050. A different view of the future. The Hague: The Netherlands Study Centre for Technology Trends (STT).
- Trendbureau Overijssel (2010). De toekomst van de landbouw in Overijssel- een discussiebijdrage. Most recently consulted on 11 December 2019 at https://wiki.p2pfoundation.net/Degrowth_Manifestohttps://www.trendbureauoverijssel.nl/verkenning/landbouw
- Wetenschappelijke Raad voor het Regeringsbeleid (2014). Naar een voedselbeleid. Amsterdam/The Hague: Amsterdam University Press.

Open Access
The Rathenau Instituut has an Open Access policy. Reports, background studies, scientific articles, and software are published publicly and free of charge. Research data are made freely available, while respecting laws and ethical research norms regarding copyright, privacy and the rights of third parties.

Contact details
Anna van Saksenlaan 51
Postbus 95366
NL-2509 CJ The Hague
The Netherlands
+31 (0)70 342 1542
info@rathenau.nl
www.rathenau.nl

Board of the Rathenau Institute

The Rathenau Instituut supports the formation of public and political opinion on the socially relevant aspects of science and technology. It conducts research and organises discussion of science, innovation, and new technologies.

Rathenau Instituut