A ROADMAP TO STRENGTHEN THE DEVELOPMENT OF THE GREENHOUSE SECTOR IN ICELAND

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1 HOW TO BUILD AN EFFICIENT AND PRODUCTIVE GREENHOUSE SECTOR: THE DUTCH GOLDEN TRIANGLE

The agriculture and horticulture sectors in the Netherlands are considered the most efficient and productive across the globe. As a matter of fact, this relatively small country is ranked as the second greatest exporter of both agricultural and horticultural goods worldwide! The farming sector is highly intensive and specialized with a high level of technologies and knowledge.

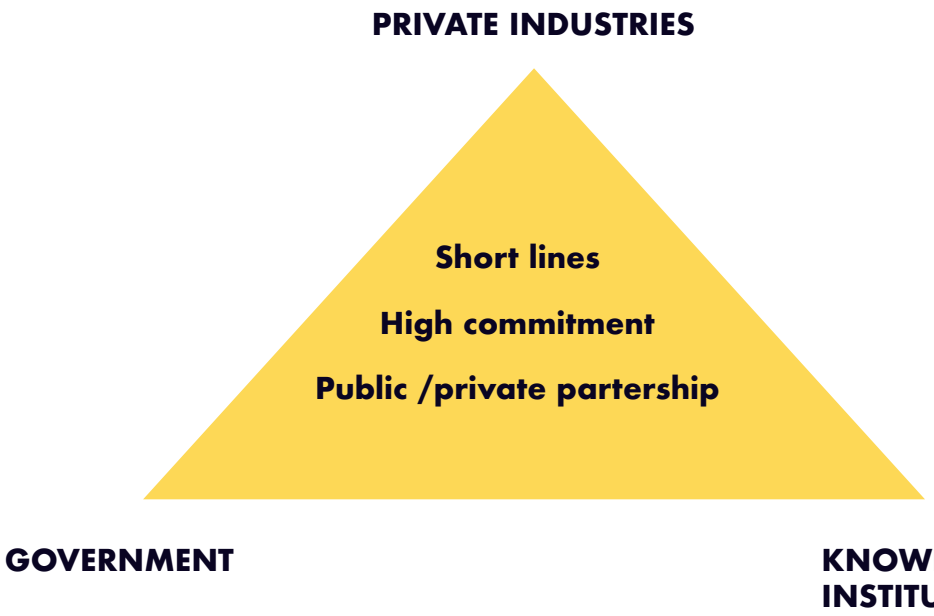

Figure 1. The Dutch golden triangle

Throughout the Netherlands, greenhouses embellish the landscapes, serving crucial purposes: efficiently meeting the nutritional demands of the Dutch population while also providing high-quality fruits, vegetables, flowers, and plants to consumers worldwide.

What are the main reasons behind this success story? For the Dutch, it can be summarized in 4 words: **the Dutch golden triangle**.

The Dutch firmly believe in the power of cooperation. The Dutch horticulture sector operates through a dynamic collaboration known as the "Dutch golden triangle" which brings together the government, entrepreneurs, and research and development (R&D) entities. This network comprises economic clusters and regions where various horticultural chains, services, and knowledge institutions synergize to drive continuous innovation in areas like robotics, plant monitoring, plant safety, and nutritional value.

Within the Netherlands, prestigious universities and institutes excel in their respective fields, such as Wageningen University & Research in food and agriculture, TU Delft, and TNO in high-tech solutions. These institutions engage in public-private partnerships with six regional Greenports and world-leading seed, supply, and technology companies. Through this collaboration, they strive to create highly efficient greenhouses that optimize limited water and resources. This shared dedication to innovation and sustainable practices underscores the essence of the Dutch golden triangle.

Iceland has privileged conditions for the development of a completely circular high tech greenhouse horticulture. The country could grow millions of tons of the healthiest and tastiest vegetables with an almost null environmental impact, unlike nowhere else in the world.

The whole world would look at the Icelandic greenhouse sector as an example of what we must do to feed the world healthily with a virtually zero footprint on the ecosystems.

However, for this to be accomplished, a replica of the Dutch golden triangles must be developed.

Some necessary tasks must be accomplished in every vertex of the triangle. Let us analyse which ones are important for the ¨Knowledge Institution Vertex¨.

In the same way that The Netherlands has Wageningen University as the head institution for research in the horticulture field, the AUI must lead the process in Iceland.

What would be needed:

- Identify the research fields that are priority for the Icelandic greenhouse sector. The fields of research should be established based on discussions between government, AUI and greenhouse producer's organizations.
- Hire young doctors to lead research and innovation programs in these fields.
- Build state-of-the-art new research facility in the AUI.
- This new infrastructure is critical, not just for horticulture developments and innovation, but also for cereals /grain cultivation – seed development and for high tech developments in biotechnology as in ORF Genetics on Plant-based Growth Factors.
- Establish a national alliance with technical Universities in the country, to enable the creation of multi-disciplinary research and innovation teams.
- Strengthen alliances with the two leading Universities in Europe on greenhouse research, both located in the two largest greenhouse regions: Wageningen University in The Netherlands and University of Almería in Spain. AUI already has collaboration agreements with both universities.

What are the critical tasks for the Government vertex?

- Stimulate and moderate the discussions between knowledge institutions (AUI and the technical Universities), growers' organizations and auxiliary industry.
- Fund the construction of a brand-new research facility at the AUI Hvanneyri.
- Fund open calls for Public-Private partnership projects. These projects must include funding for PhD students (salary, stays in foreign Universities).
- Fund two yearly exchange seminars, one with the participation of Wageningen UR and one with the University of Almeria, where both Icelandic researchers and local researchers from these two Universities will present results of their ongoing research programs. The meeting would be held, alternating one year in Iceland, one in the destination Universities.

Finally, the third vertex, represented both by growers' associations and private auxiliary industry. They must collaborate with the other two vertex of the triangle. Growers' associations must be involved in the public-private partnership projects, both in kind and in cash. Municipalities in the regions where greenhouse development is more favoured by local conditions (logistics, availability of resources, etc.) could and should also be involved.

Without the golden triangle, it will be unlikely that the greenhouse sector in Iceland can grow and acquire the relevance required to start exporting to the world the more sustainable and circular vegetables produced in this planet.

Without the golden triangle, most greenhouse projects will be of very limited size, trying to fill the relatively small local demand and will completely rely on foreign technology, which will not have taken in consideration the special conditions of Iceland, which both pose opportunities and challenges.

2 THE SPANISH, DUTCH AND ICELANDIC GREENHOUSE SECTOR

The two main greenhouse regions in Europe are both near the sea, one is near the Mediterranean, in Almeria, the eastern province of Andalucia, in Spain. The other is near the North Sea, the Westland district in The Netherlands (Figure 2).

A) THE ¨PLASTIC SEA¨ OF ALMERÍA IN SPAIN.

B) THE ¨GLASS SEA¨ OF THE WESTLAND IN THE NETHERLANDS.

Figure 2. Satellite pictures of the two largest greenhouse regions in Europe.

They are both the two most paradigmatic examples of successful development of greenhouse horticultural sector. Compared to these two giants, the greenhouse area of Iceland seems insignificant (Figure 3).

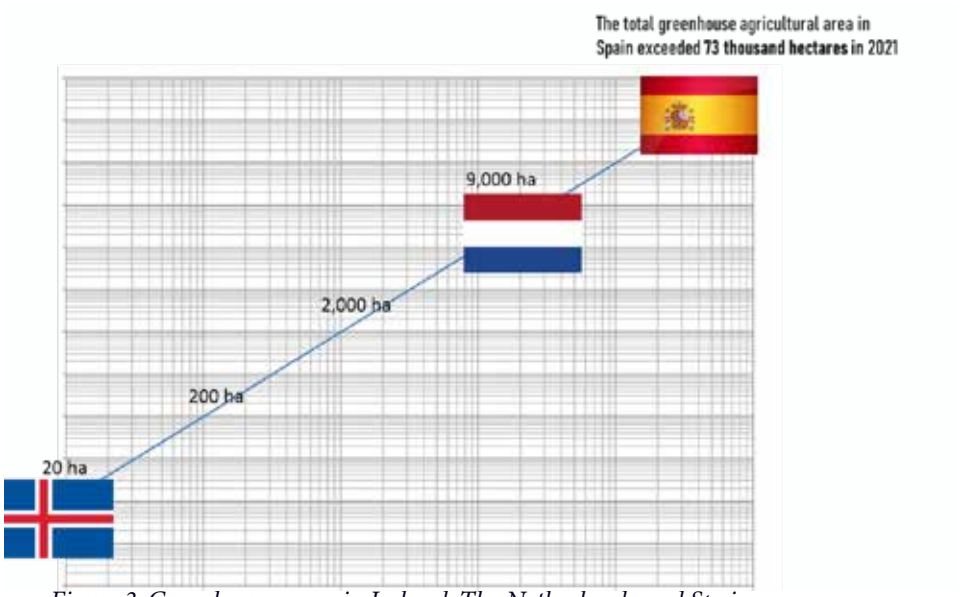

Figure 3. Greenhouse areas in Iceland, The Netherlands and Spain.

2.1 The Spanish greenhouse sector at a glance.

In Spain, greenhouse cultivation only accounts for 0.27% of the 23.9 million hectares of agricultural area in Spain, with 73,000 Ha in 2021. Almost nine out of every ten hectares of greenhouses are devoted to vegetables, although woody crops, flowers, seeds, and aromatic, medicinal plants, and spices are also produced.

86% of the greenhouse area is in the Southeast of the country (provinces of Almería, Granada and region of Murcia) (Figure 4). Only in the South of the country, there are more than 60,000 Ha of greenhouses.

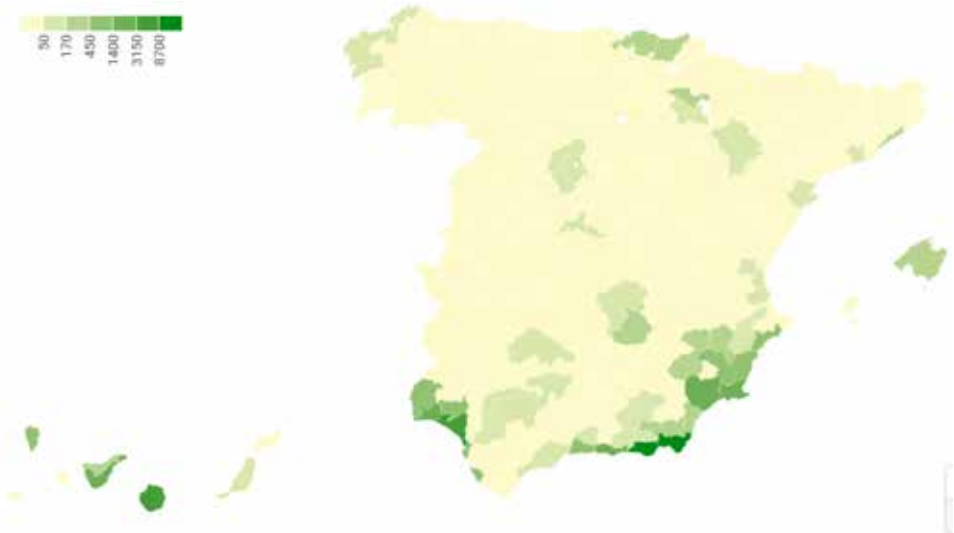

Figure 4. Distribution of greenhouses in Spain

The largest greenhouse concentration is found in the province of Almería, with more than 30,000 Ha. Agriculture contributes to 40% of the GDP, being the main economic engine of the province. The greenhouse sector is a family economic model where income

is distributed equitably to some 14,000 families. Promoting local employment and family economy. The greenhouse sector generates a total of 110,000 jobs. Of this workforce, 78,000 workers are related to farms (cultivation, irrigation, harvesting, etc.), 24,000 with marketers (handling and distribution) and 8,000 with auxiliary agricultural companies (seeds, manufacturers of plastics, packaging, agricultural machinery, biological control, environmental control, etc). On season 2021/2022, 3,494.83 million kilos were produced for a value of 2,786.95 million euros. In addition, the auxiliary industry generates more than 1.3 billion Euros.

Almeria greenhouses are simple, nothing like the sophisticated and highly technified greenhouses of the northern countries, such as The Netherlands, or Iceland.

The reason why greenhouses are so simple in Spain is the mildness of the Mediterranean climate and the avoidance of summer production. Spanish greenhouses produce mainly during the winter period, when production in the Northern countries is limited, because a lot of energy is required for heating and artificial light.

A typical greenhouse farm of Almería can be described as follows:

- The average size is 2.3 Ha.
- Artisan greenhouse metallic (or wood) greenhouse structure.
- Covered with a polyethylene plastic film.
- It has simple roof and sidewall vents which are opened and closed manually.
- It does not have other type of climate control equipment (heating, cooling, CO_2 enrichment, etc.).
- The crop is cultivated directly in an artificially created soil, known as ¨enarenado¨ which has a sand mulch on top of the soil.
- Pests are controlled with integrated pest management programs that combine biological control with low environmental impact chemical control.
- In periods of high radiation, early autumn and spring, the roof is painted with chalk to shade the plants and reduce thermal stress.
- Growers have IoT systems and simple sensors (e.g. tensiometers) to know when and how much to irrigate.
- The two main crops are tomato and sweet pepper.

The philosophy of the growers is to adapt the plant to a greenhouse climate which is normally sub-optimal. The yields are low, but the cost prices are also low when compared with northern greenhouses.

As an example, a Spanish grower harvests on average 15 kg of round tomato per square meter, while a Dutch grower can harvest 68 kg/m^2.

2.2 The Dutch greenhouse sector at a glance.

After the United States, the Netherlands is the biggest exporter of agricultural produce in the world. The Dutch agricultural sector exports some € 65 billion of agricultural produce annually. This is 17.5% of total Dutch exports. Accounting for 10% of the Dutch economy and employment, the agricultural and horticultural sectors play a crucial role.

Horticulture plays a significant part in bolstering the Dutch economy, making substantial contributions to various aspects of the country's prosperity. With the sector accounting for approximately 2.7 percent of the Gross Domestic Product (GDP), amounting to €21.1 billion, it proves to be a vital economic pillar. Moreover, horticulture is responsible for employing 3.4 percent of the workforce and uses 4.5 percent of the nation's expenditure on research and innovation.

Among the diverse components of the horticulture sector, greenhouse horticulture stands out as a crucial element. Contributing 1 percent to the GDP and generating an impressive export value of €9.2 billion, it holds great significance in the broader horticultural landscape.

The greenhouse area in The Netherlands is rather stable during the last decades, oscillating around 10,000 Ha (Figure 5), nowadays stabilized in 9,000 Ha.

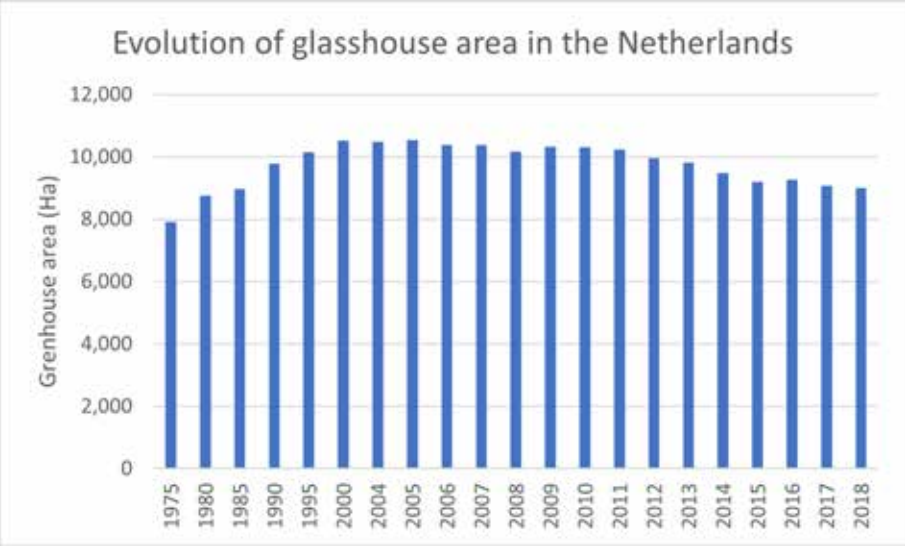

Figure 5. Evolution of greenhouse area in The Netherlands

Approximately 45 percent of this area is dedicated to vegetable production, while the remainder is utilized for flower and fruit cultivation. Most of these greenhouses are concentrated in the region of the Westland (Figure 6).

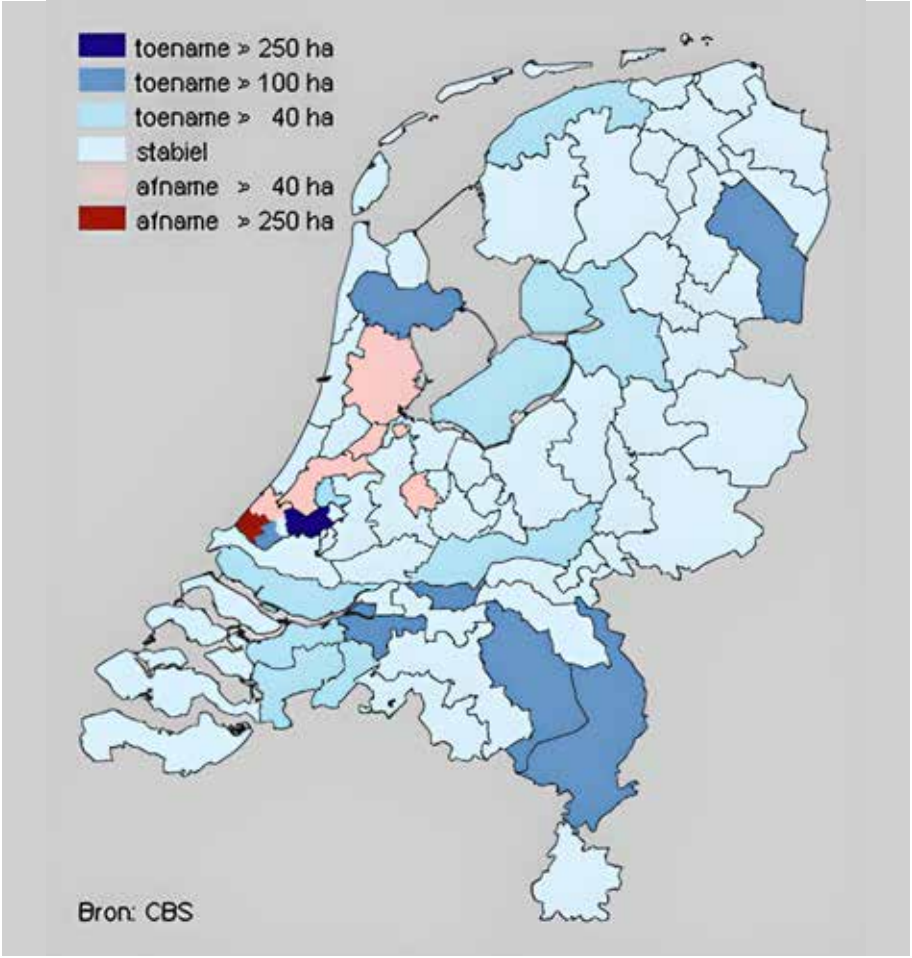

Figure 6. Distribution of greenhouses in The Netherlands

The average utilized agricultural area per greenhouse horticulture farm in the Netherlands more than doubled from 2007 to 2021. In 2007, the average farmland per greenhouse horticulture farm in the Netherlands was 2.6 hectares. By 2021, this average had increased to approximately 6.1 hectares (Figure 7).

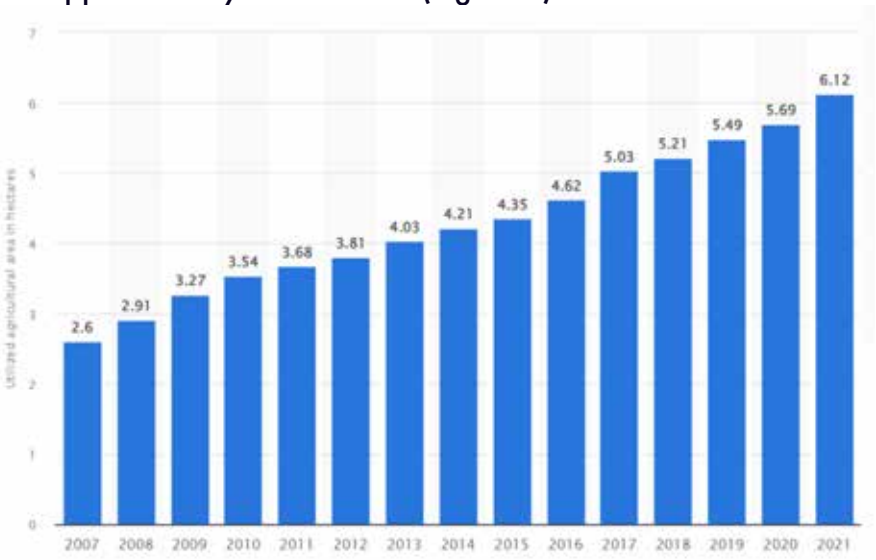

Figure 7. Average utilized agricultural area per greenhouse horticulture farm in the Netherlands from 2007 to 2021

The Dutch greenhouses' production intensity and scale have positioned them as dominant players in the European market. Remarkably, they account for 21 percent of Europe's pepper production, 20 percent of cucumber production, and 17 percent of tomato production. Such impressive figures exemplify the nation's progress in greenhouse agriculture.

Despite their remarkable productivity, greenhouses consume a significant amount of energy, becoming intensive energy consumers. As of 2019, the total energy consumption in the Dutch greenhouse sector was a staggering 106 petajoules (PJ). A considerable portion of this energy is utilized for heating purposes, and natural gas overwhelmingly dominates the energy sources used. Notably, around 58 percent of the electricity required is produced within the greenhouses through cogeneration, with most greenhouses having on-site combustion plants. The remaining 42 percent is purchased externally.

In recent years, the Dutch greenhouse sector has been making commendable strides in adopting renewable energy sources, primarily focusing on geothermal energy. This shift towards sustainable alternatives has been witnessing rapid growth, signalling a positive commitment towards environmental conservation, and reducing reliance on non-renewable resources.

So, the growing philosophy of Dutch growers is trying to maintain optimum conditions for the crop during as much time as possible. This approach requires technology and fossil energy.

Although, Dutch glasshouses are more diverse than Spanish greenhouses, and can have different degrees of automation, a typical Dutch vegetable glasshouse can be described as:

- Average farm size is 6.1 Ha
- It uses the well-known Venlo greenhouse structure.
- It is very high, gutter height being 6.5 m or more.
- It is covered with glass.
- It has a heating system with hot water, which is usually heated in a boiler or a co-generation system burning natural gas.
- It has a hot water buffer to store hot water and a system to use the CO_2 generated in the combustion of the natural gas.
- It has a CO_2 distribution system.
- It has one or two screens for energy saving.
- It has automated roof natural ventilation.
- The crops are grown on a substrate (rockwool) and drainage is re-used in a closed system.
- Pest and diseases are managed with IPM programs that use biological control and low impact chemicals.
- Climate is carefully monitored and controlled by a computer system.

3 THE ICELANDIC GREEN-HOUSE SECTOR

In 2017, a total of 11.8 Ha of land was dedicated to vegetable production in greenhouses in Iceland (Orkustofnun, 2017). Today there are approximately 60 greenhouse farmers in Iceland. The number of farms has decreased, and the biggest companies have been increasing the greenhouse area and implemented new technologies. There are still several small farmers (few thousand m^2 production area) and a few (appr. 10) larger producers (ca. 1 Ha) some integrating tourism / restaurant services. In comparison the average farm size in the Netherlands is 6.1 Ha and the ten largest are in total 500 Ha.

Figure 8 shows the production in tonnes of the main crops during the last fifteen years (2008-2022). The production has been quite stable during the period despite the increasing number of habitants in Iceland and the blooming tourism industry.

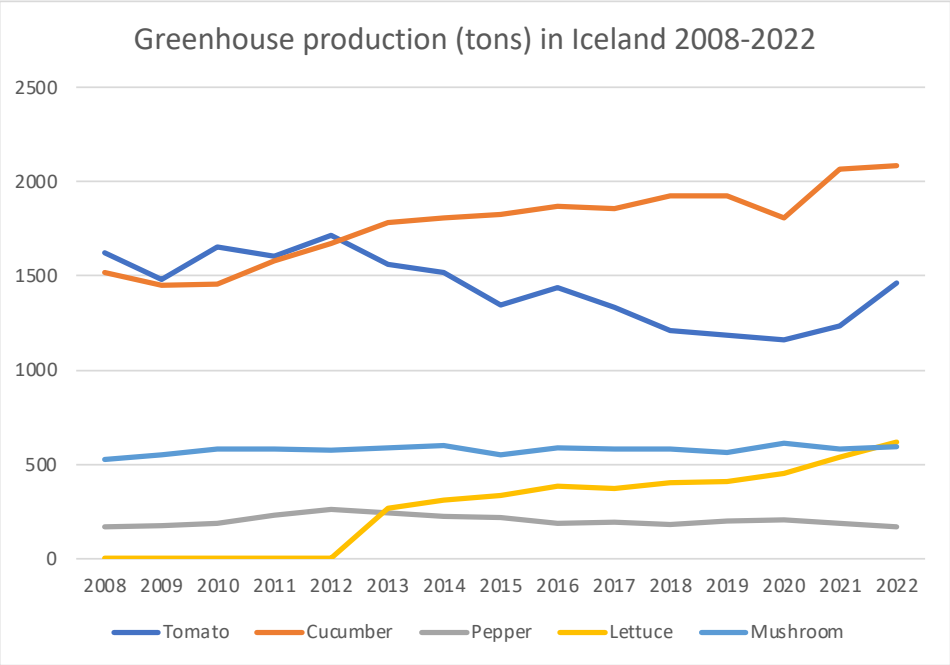

Figure 8. Horticulture production in Iceland 2008-2022 (Hagstofan.is)

Icelandic greenhouses, are similar in many aspects to Dutch greenhouses, they also have some interesting differences:

- They are small, usually less than 0.5 Ha.
- They are not as high as in The Netherlands and often older constructions.
- They do not have a boiler or a CHP system, because they use geothermal water directly for heating.
- They use CO_2 for carbon dioxide enrichment.
- They have artificial lighting system of high capacity (>200 micromol/m^2) to provide enough light for producing in the middle of the dark Icelandic winter.
- They do not have energy saving screens or any other energy saving equipment.
- Incidence of pest and disease is very low due to the cold climate.

To be added to the AUI new research facility

The new research facilities needed in the AUI are key for the greenhouse horticulture development in Iceland, but they have also other strategic uses of great importance:

1. They can be used for breeding and seed production for cereal crops.

Iceland holds the distinction of being the northernmost nation engaged in grain farming globally, and grains can be cultivated across various parts of the country, although specific regions exhibit greater suitability than others. In Iceland's context, barley and wheat are the predominant grain varieties produced, although certain farmers have also ventured into experiments with oats and rye.

Ensuring the preservation of national cereal crops and addressing their associated research requirements requires a commitment to sustained funding over the long term. It is essential, thus, finalizing the construction of the Agricultural Research Centre to effectively conduct the breeding, research, development, and educational activities within this domain.

2. Biotechnology and molecular farming

The genetical modification of plants to produce specialty proteins is called molecular farming. ORF genetics, an Icelandic company, uses barley grain as a vehicle for production of recombinant human and animal proteins. This has resulted in an extensive portfolio of recombinant proteins for stem cell technology research, skincare, biopharma, and the cultured meat market.

The new research facility must provide support, so that these modified plants can be all grown under the desired climate and nutritional conditions.

The world is demanding more and more high quality safe food, and fruits and vegetables are among the most demanded. Despite of this, we have seen empty shelves in the European supermarkets last year.

The main greenhouse areas in Europe are facing important threats that may limit their preponderance in the coming years.

In Spain, the scarcity of quality water for irrigation is the major threat. So far, it has been partially solved by building desalinating plants, but the impact of the brine on the local sea ecosystems could limit their operation in coming years.

In The Netherlands, the main limiting factor is the large dependence on fossil fuel. We have already seen the result of increased price of natural gas last year: many greenhouse farms were not cultivated, and others switched to less heat dependent crops or had to grow shorter cycles. Despite of the R&D efforts to minimize this dependency, making the required investments on technology to eliminate fossil fuel dependence would take years. Other threats as the availability

of labour and competition for the land are also challenging their greenhouse sector.

In this context, a country like Iceland, stands as an alternative location to produce fruits and vegetables in high tech greenhouses and export them to both Europe and USA/Canada. Located halfway between Europe and America and, despite of its northern location and cold climate, it has abundant resources that would allow for cultivation of the highest quality vegetables in a real circular fashion: abundant land, green energy and high-quality water, unlike in no other location on earth. Labour is scarce, but it could be outsourced from third countries in a controlled immigration program, as well as with the partial implementation of automation and robotization for crop tasks.

For this to happen, the Icelandic government should take the necessary steps to enable the development of a suitable ecosystem as an image of the Dutch golden triangle. The Agricultural University of Iceland, together with the rest of Icelandic Technical Universities must become uno of the vertexes of the triangle, with government and growers on the other two vertexes.

The construction of new greenhouse research facilities in AUI is of primordial interest. In this new facility, the research and innovation demand of greenhouse farmers would find an answer. Such facility is also of vital to keep developing breeding programs for cereals and for molecular farming. Finally, it is vital to be able to make real exchange R&D greenhouse programs with both Dutch and Spanish Universities.

The new facilities could be one of the catalysers for a process that could amaze the world: the Icelandic Greenhouse uprising.