# Market potential and investment opportunities of high-tech greenhouse vegetable production in the USA

An exploratory study for Midwest and East Coast regions and the state of California

Marc Ruijs, Jan Benninga

WAGENINGEN UNIVERSITY & RESEARCH

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This study was carried out by Wageningen Economic Research and was commissioned and financed by the Dutch Embassy in Washington, Dutch Consulate in Chicago, Netherlands Enterprise Agency and NL Works.

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Een verkennende studie is uitgevoerd naar de marktpotentie van hightech kassen in de regio's Midwest en East Coast en de staat Californië van de Verenigde Staten (VS) en de investeringskansen voor het Nederlands tuinbouw toeleverend bedrijfsleven. Inzicht wordt gegeven in de productie, import en consumptie van (verse) vruchtgroenteproducten in de VS. Geschat is welke omvang de hightech kastuinbouw in de VS (qua areaal en investeringen) in theorie kan hebben als de import vanuit m.n. Mexico en Canada wordt vervangen door eigen productie. Vervolgens is indicatief aangegeven welke investeringskansen dit het Nederlands toeleverend bedrijfsleven kan bieden.

An exploratory study was conducted into the market potential of high-tech greenhouses in the Midwest and East Coast regions and the state of California in the United States (USA) and the investment opportunities for Dutch horticultural supply companies. Insight is given into the production, import and consumption of (fresh) fruit vegetable products in the US. It is estimated how large the high-tech greenhouse horticulture in the USA (in terms of acreage and investments) can theoretically have if the imports from Mexico and Canada are replaced by their own production. It is then indicated indicatively which investment opportunities this can provide to Dutch suppliers.

Key words: Production, consumption and market analysis of (fresh) vegetables, regions Midwest and East Coast and the state California, greenhouse investments opportunities for Dutch horticultural suppliers

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# Preface

This study explores the market potential of high-tech greenhouses for (fresh) vegetable production in the Midwest and East Coast region and California of the United States of America (USA). It also assesses the business and investment opportunities for the Dutch greenhouse supplying industry. The assignment has been issued by the Royal Netherlands Embassy in Washington and the Dutch Consulate in Chicago. The project was financed by previous parties and with support of the Netherlands Enterprise Agency and NL Works.
Wageningen Economic Research was contracted to conduct this exploration study.

The outcome is a report of a desk study, based on literature search, statistics and impressions in magazines and consultations of stakeholders.

The deliverables of the exploratory study will support producers and potential producers in investing in vegetable greenhouse production, Dutch suppliers in intensifying their activities in the USA and national and regional policymakers and Dutch agricultural counsellors in facilitating the horticultural sector.

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# Summary


## S.1 Primary outcomes

There is a clear potential for high-tech greenhouse vegetable production in the USA, provided that market requirements can be met. The most important aspect is entering into contracts with retailers. Preferred is a construction in which deliveries are made at fixed prices with defined product quality criteria. It is the combination of competitive prices and to be delivered services (designing, building and maintenance) which determines whether the Dutch greenhouse industry can benefit from the demand for greenhouse horticultural development in the USA.

The advantages of protected cultivation compared to outdoor production of vegetables are the mostly better product quality and higher input efficiencies of water, nutrients and crop protection agents (physical consumption related to level of yield). Moreover, protected cultivation is less dependent on the climate factor and ensures the delivery of products in time. Disadvantage of protected cultivation is the use of energy and related emission of $CO_2$. This environmental impact can be reduced largely in different ways, but cannot be neglected.

The potential greenhouse area to substitute imports of fresh vegetables into the USA is calculated at 7,000-8,000 ha. This area corresponds with a total investment sum of USD 9,575-10,915m. A rough estimation is that Dutch greenhouse constructors could reach a share of 5-10% of this potential investment sum. This is 10-20 times higher than the current export of greenhouse materials to the USA.

## S.2 Other outcomes

The positive perspectives of greenhouse production of vegetables in the USA also offer opportunities for export from the Netherlands of other horticulture input suppliers like seeds, fertilisers and crop protection agents (including biological control).

The estimated area of greenhouse horticulture establishments will provide 56.5-58.5m hours of employment, of which more than 90% for cultivation labour. The question is whether the required (unskilled and skilled) labour can be provided locally, regionally or nationally or whether labour migrants from other countries might be needed.

The opportunities for establishing high-tech greenhouses in the Midwest and East Coast region and the state of California are related to local and regional biophysical conditions such as climate, infrastructure (roads and resources) and distance to the markets. This might be worked out in more detail in a follow-up of this study, in which the feasibility can be determined more concrete.

No firm conclusions can be drawn, because the study is an exploration of the potential and opportunities. There are many (biophysical and social) factors that determine how the opportunities can be capitalized.

## S.3 Method

They study is commissioned and financed by the Dutch embassy in Washington and the Dutch Consulate in Chicago, the Netherlands Enterprise Agency and NL Works. An exploratory study has been conducted by Wageningen Economic Research about the perspectives of high-tech greenhouse horticulture in the USA and the opportunities for the Dutch horticultural industry. Recent data have been gathered from Dutch and American statistical sources and information has been collected from various reports and magazines.

# 1 Introduction

## 1.1 Background

The rural situation of the Midwest region of the United States of America is apparently difficult for transforming agricultural sectors towards more sustainable and competitive production (Schneider, 2019b; E. Breman (Dutch embassy Washington) in interview with author; J. Webb and D. Nichols (AppHarvest) and J. Ball (SOAR) in interview with author). One of the options to achieve this is protected cultivation or greenhouse production. Interest in greenhouse production is caused by various factors. For example, the demand for fresh and locally produced (organic) vegetables is increasing, driven by a growing consumer demand on healthy food and food safety. In addition, the availability of sufficient and qualified labour is a huge challenge for American agriculture and increasingly extreme weather conditions make US food production vulnerable. Competition with imports from countries with lower production costs, especially from Mexico, is a serious threat in competitive strength but also from an environmental point of view (footprint).

Especially in the state Kentucky, high-tech greenhouse production has gained much attention by public and private sector. Financers and venture capitalist are (still) hesitating to step into the greenhouse sector because of unfamiliarity with the concept of high-tech vegetable production in a controlled environment (Client and J. Webb (CEO AppHarvest) in interview with author).

Some of Kentucky's representatives are impressed by the Dutch greenhouse industry and their successes (National Geographic, 2017; Schneider, 2019a). Kentucky and some other regions and states are looking to collaborate with Dutch horticultural companies in establishing a sustainable and commercial vegetable production.

The federal minister of Agriculture, Sonny Purdue, is also very much interested in the Dutch greenhouse sector. During the annual USDA Agricultural Outlook Forum in Virginia in 2020 he presented the new agricultural innovation agenda. The Netherlands is seen as a role model and important contributor to reducing the ecological footprint and to gain the necessary productivity increase for American agriculture for the coming thirty years (Schneider, 2019b).

Another reason for this study is to become less dependent on the imports of Mexican and Canadian fresh vegetables such as tomatoes, peppers and cucumbers in combination with the search for year-round jobs for unemployed people, due to e.g. the closing of mining factories in some states of the USA such as Kentucky.

## 1.2 Objectives

The objective of this study is to explore the market potential of high-tech greenhouses for (fresh) vegetable production the Midwest, East Coast region and the state California of the USA, which has special interest by the Dutch embassy. Moreover, this exploration study will assess the investment opportunities for Dutch companies of the horticultural supply chain.

The deliverable is a report with the outcomes of the exploration study and will be used to indicate the opportunities of greenhouses production of (fresh) vegetables in the selected states of the USA. This information helps (potential) producers, financers and venture capitalists to determine their investment strategy towards high-tech greenhouse production. Furthermore, it will support Dutch horticulture suppliers to focus on the American market for greenhouse production and their contribution/share to this development.

To provide a good overview, the study is focused on the states of Florida, California, Kentucky and New Hampshire, in which regional spread is aimed. The results of these states are more or less representative for the other states in the Midwest and East Coast region.

## 1.3 Reading guide

After the introduction chapter, in Chapter 2 the method will be described. Chapter 3 includes a description of the Dutch high-tech greenhouse sector, specialised in fresh vegetables. The optimal conditions for vegetable production and the volume of production and consumption of fresh vegetables in the USA is described in Chapter 4. Chapter 5 treats the assessment of the investments in greenhouses. The discussion and conclusions are mentioned in Chapter 6 and, finally, Chapter 7 presents the recommendations.

# 2 Methods

This exploration study has been conducted as a desk study. At first attention was paid to the market potentials of protected cultivation and the opportunities for the Dutch supplying industry, later on also environmental aspects got more attention.

For an overview of the Dutch greenhouse vegetable sector and supply chain data from agrimatie.nl, the Agro & Food portal of Wageningen Economic Research, have been used. This portal gives insight into the performances of the Dutch agricultural sector. The information is based on about 1,500 agricultural farms, of which about 260 farms from the greenhouse horticultural sector.

For the situation in the USA and the trade relation between the Netherlands and the USA, information and data have been gathered through a literature search with a variety of sources including Dutch national statistics (CBS/Wageningen Economic Research, national (USA) and international trade statistics (Comtrade, Comext, etc.), magazines, information of the Dutch embassy in the USA and consultations with stakeholders in the Netherlands and the state of Kentucky. In that context a meeting with the delegation of public and private companies from Kentucky and the Dutch counsellor in the USA, who visited the Netherlands in February this year, was an important input for this study.

An estimation of the investments in high-tech greenhouse establishments was based on of the publication 'Kwantitatieve Informatie voor de Glastuinbouw' (Raaphorst and Benninga, 2019), additional information from Dutch greenhouse constructors and figures about the production and imports of the main fruit vegetable products (tomato, bell pepper and cucumber). Investment opportunities for other links in the supply chain (breeders, suppliers of inputs like fertilisers and crop protection) were assessed by using above estimates and current exports of agriculture-related goods to the USA.

In this exploratory study figures are used and estimations are made for an average or general situation. No differences are made related to differences in climate and other bio-physical conditions between the different regions and states, because this requires more in-depth research and more time to elaborate on it.

# 3 High-tech greenhouse vegetable production in the Netherlands

In this chapter the structure, economic and sustainable performance of the Dutch greenhouse vegetable sector are described.

## 3.1 Structure

As can be seen from Figure 3.1 the number of farms has reduced dramatically, while the average area of farms has increased tremendously from 0.95 ha in 2000 to about 2.8 ha in 2019.

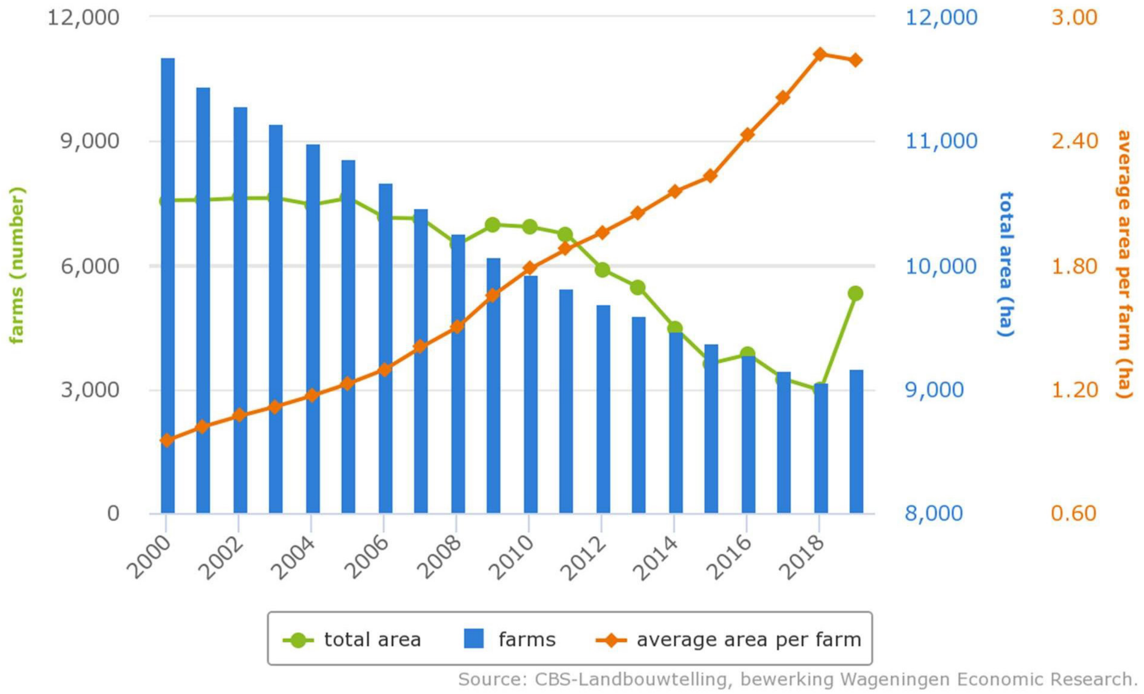


***Figure 3.1*** *Number of farms, area and area per farm of greenhouses horticulture in the Netherlands*
*Source: CBS-Landbouwtelling, adapted by Wageningen Economic Research.*

Between 2012 and 2018 the total area of greenhouse horticulture has declined steadily, but since 2018 it has increased strongly again to about 9,780 ha in 2019.

The greenhouse sector in the Netherlands is divided into vegetables, cut flowers, potted plants and some fruit and nursery plants under cover.

As can be seen from Figure 3.2 the vegetables under glass also show a strong decrease in the number of farms, but the average size of farms has sharply increased from 1.2 ha in 2000 to about 4.4 ha in 2019, which means it has almost quadrupled in 20 years.

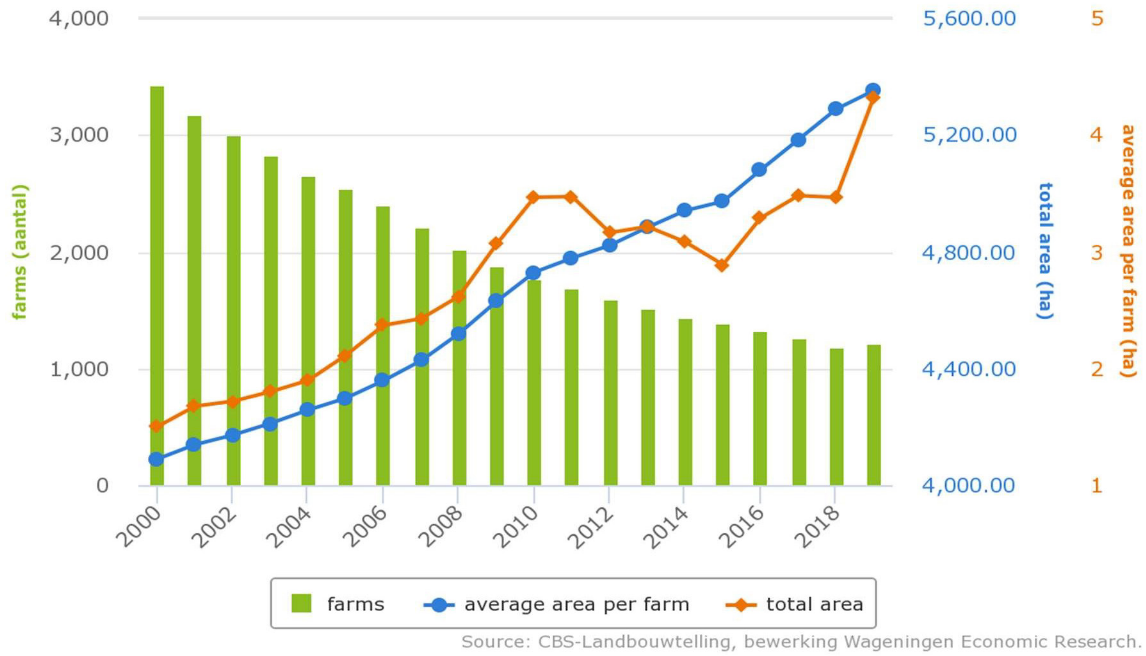


***Figure 3.2*** *Number of farms, area and area per farm of greenhouses vegetables in the Netherlands Source: CBS-Landbouwtelling, adapted by Wageningen Economic Research.*

The total area of vegetables increased from 2000 to 2011, but declined after the economic crisis in the period 2010-2013. Since 2015 it has increased sharply to about 5,330 ha in 2019, but this increase will stagnate this year because of the Covid-19 outbreak. Almost 85% of greenhouse vegetable farms in 2019 are specialised in vegetable production.

The main vegetables in the Netherlands are tomatoes, sweet peppers, cucumbers and strawberries. Specific developments for these crops are illustrated in Appendix 2. The individual vegetable crops show a similar pattern as the total greenhouse vegetables. Only the total area of cucumber production has decreased strongly after 2010, while the total area of strawberry shows a steady growth year after year. For all vegetables, the average size of farms has increased and the strongest increase is reported for tomatoes (average farm size is now 6.7 ha in 2019).

Although there is a limited area of mid-tech greenhouses with lettuce, other leafy vegetables and radish with soil cultivation at low daily temperatures of 8ºC, the most common greenhouses are high-tech (90%). Roughly speaking the following distinction can be made between low-, mid- and high-tech greenhouses:

- low-tech: plastic structures with low-tech cultivation systems
- mid-tech: plastic structures with limited environmental control and mid-tech cultivation systems and
- high-tech: mainly glass structures with high degree of active environmental control, automation and high-tech cultivation system (Ruijs, 2018).

A high-tech greenhouse is a protected and controlled environment for controlling the greenhouse climate, integrated pest management, ferti-irrigation and applying modern cultivation techniques and methods. The main purpose of high-tech greenhouses is to create a production system, with which the yield and quality of the determined product can be obtained at the right time. For a detailed description of the high-tech greenhouse, see Appendix 1.

The most common greenhouse in the Netherlands is the Venlo type (see Figure 3.3).

***Figure 3.3*** *Typical Venlo type greenhouse*
*Source: Shutterstock.*

For an average vegetable high-tech greenhouse the new value and annual costs of a standard farm set-up is shown in Table 3.1 for different farm sizes. Table 3.1 shows that the economics of scale is still present for a basic greenhouse production unit. Unfortunately, figures for larger sizes were not available. Looking into practice it is plausible that the optimum size of a greenhouse production unit is about 20,000 m².

***Table 3.1*** *New value and annual costs for a standard vegetable greenhouse type, an additional CHP and additional artificial lighting in euros (excluding soil)*

| Size (m² greenhouse area)<br>Business type | 10,000 | 15,000 | 20,000 | 40,000 | 100,000 |
|---|---|---|---|---|---|
| **1.Vegetable, heating pipes, rockwool, recirculation** | | | | | |
| New value | 1,347,900 | 1,801,400 | 2,286,600 | 4,124,400 | 9,445,000 |
| Depreciation costs | 125,500 | 167,000 | 212,400 | 383,600 | 876,700 |
| Interest costs (2%) | 14,800 | 19,800 | 25,200 | 45,400 | 103,900 |
| Maintenance costs | 33,600 | 42,600 | 54,400 | 94,600 | 208,400 |
| Total annual costs | 173,900 | 229,400 | 292,000 | 523,600 | 1,189,000 |
| Per m² | 17.40 | 15.30 | 14.60 | 13.10 | 11.90 |
| **7. CHP 0,5 $MW_{el}$/ha 3,000 hours/year** | | | | | |
| New value | 341,000 | 368,000 | 394,000 | 683,000 | 1,707,500 |
| Depreciation costs | 17,050 | 18,400 | 19,700 | 34,150 | 85,375 |
| Interest costs (2%) | 3,800 | 4,000 | 4,300 | 7,500 | 18,800 |
| Maintenance costs | 17,500 | 26,250 | 29,750 | 49,000 | 122,500 |
| Total annual costs | 38,350 | 48,650 | 53,750 | 90,650 | 226,675 |
| Per m² | 3.80 | 3.20 | 2.70 | 2.30 | 2.30 |
| **8 Artificial lighting 55 W/m² 100 µmol/sec/m² 3,000 hours/year** | | | | | |
| New value | 144,700 | 217,100 | 289,500 | 578,900 | 1,447,400 |
| Depreciation costs | 17,400 | 26,100 | 34,700 | 69,500 | 173,700 |
| Interest costs (2%) | 1,600 | 2,400 | 3,200 | 6,400 | 15,900 |
| Maintenance costs | 1,400 | 2,200 | 2,900 | 5,800 | 14,500 |
| Total annual costs | 20,400 | 30,700 | 40,800 | 81,700 | 204,100 |
| Per m² | 2.00 | 2.00 | 2.00 | 2.00 | 2.00 |

Source: Raaphorst and Benninga (2019).

# 3.2 Economic performance

In 2017, the Dutch agro-complex's contributions to the Dutch economy's added value and employment amounted to 7% and 8% respectively (last presented figures). In addition to the agricultural and horticultural sector, the agro-complex also encompasses the processing and distribution of agricultural products and the supply of the products and services required to produce these agricultural products, such as energy, artificial fertiliser, animal feed and business services.

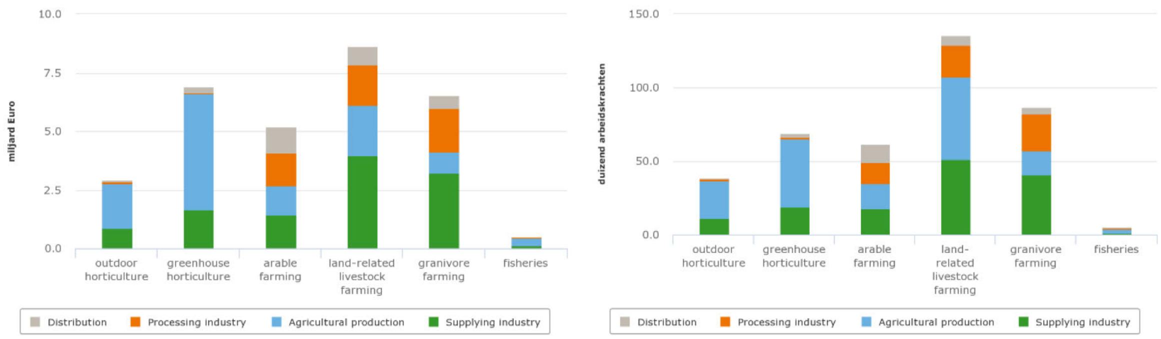


***Figure 3.4*** *Economic importance of different agricultural sectors and the distribution within the chain in the Netherlands in 2017 (agrimatie.nl)*

Figure 3.4 shows that the greenhouse horticultural complex is ranked second in added value and third in employment in Dutch agriculture. Within the greenhouse horticultural complex, the production sector and the supplying industry contribute most to the economic importance. The distribution and especially the processing industry are of minor relevance.

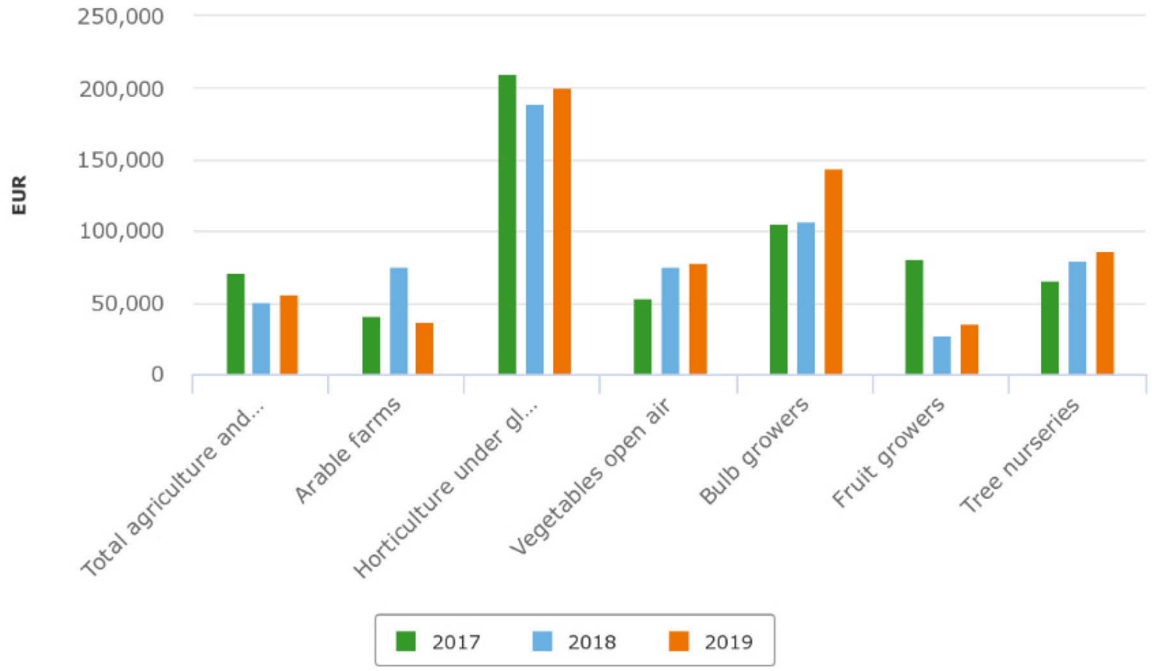


***Figure 3.5*** *Family income per unpaid labour working unit (euro) (agrimatie.nl)*

Figure 3.5 indicates that the greenhouse horticultural sector has, in general, a higher family income per unpaid labour working unit in comparison to other crop sectors, such as bulbs, tree nurseries and outdoor vegetables.

Since 2014 the distribution of family income has increased sharply, like the greenhouse vegetables (see the lower level (representing – 20% of the farms has a lower family income) and the upper level representing 20% of the farms has a higher family income in Figure 3.6). The strong growth in size per farm has contributed to this distribution largely.

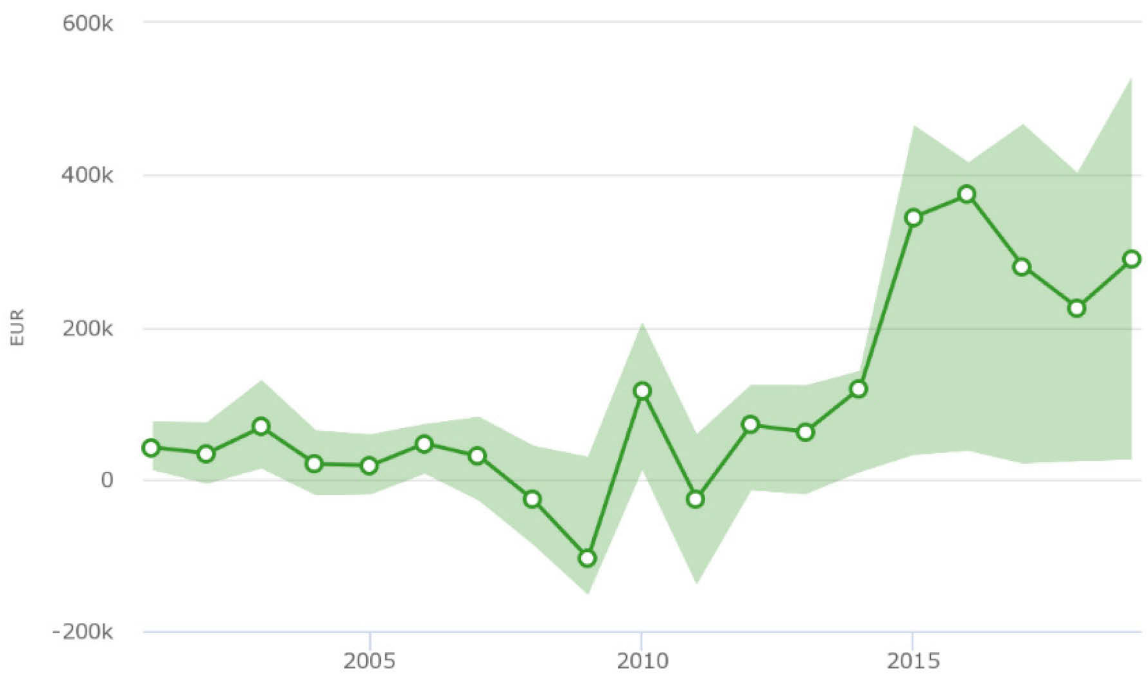


***Figure 3.6*** *Family income per unpaid labour working unit and the lower (20% level) and upper level (80% level) (euro) (agrimatie.nl)*

The family income is to a large extent dependent on the balance of the total output and total costs. An overview of the annual output and costs per farm type is illustrated in Figure 3.7.

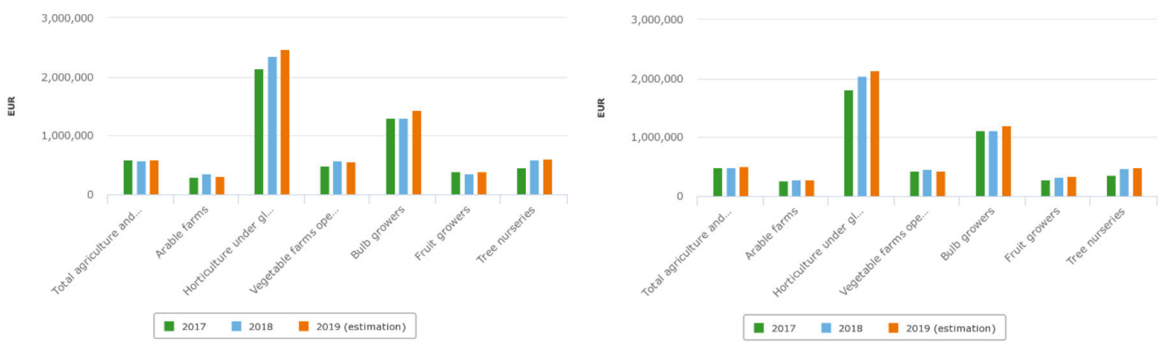


***Figure 3.7*** *Development of average total output and average costs per farm of crops sectors (euro) (agrimatie.nl)*

The total output and total costs per farm type follow the same pattern and it emphasises the higher level of technology in greenhouse horticulture (more capital intensive).

Global costs per farm for greenhouse vegetables and outdoor vegetables are shown in Figure 3.8.

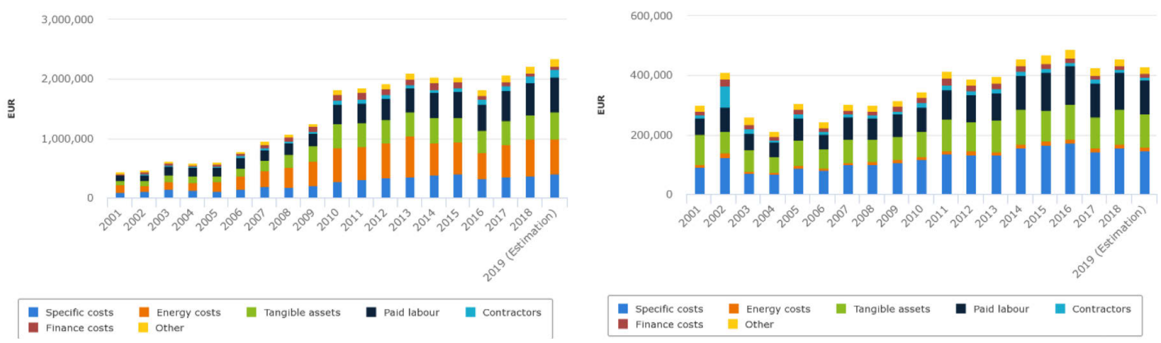


***Figure 3.8*** *Average costs component of greenhouse vegetable farms and outdoor vegetables farms (euros) (agrimatie.nl)*

As can be expected the total costs of greenhouse vegetable farms are to a substantial part determined by the energy costs than of outdoor vegetable farms. The costs have increased strongly after 2005 because of the expansion of farm size. This development was partly made possible by the government and the financial sector through stimulation programmes (appointing new locations for sustainable greenhouse production) and a new financing product (lease-back structure).

In more detail the average output, costs and financial results of greenhouse vegetable and outdoor vegetable farms are illustrated in Table 3.1. These figures are estimates for 2019, but give an impression of the type and the level of the output and costs. As mentioned before greenhouse vegetable farms are more intensive or capital intensive than outdoor vegetable farms and therefore show a much higher level of output and costs, which is also illustrated by the holding size and intensity. Table 3.1. offers insight into the separate costs of production.

***Table 3.1*** *Farm structure and financial results of greenhouse vegetable and outdoor vegetable farms (results on farm level), euros*

| Variables | Horticulture under glass: vegetable farms | Open field vegetable farms |
|---|---|---|
| **Output** | | |
| *Total output* | 2,800,700 | 555,100 |
| Vegetables | 2,161,800 | 483,400 |
| Tomatoes | 1,139,800 | 0 |
| Cucumber | 350,700 | 0 |
| Red pepper | 494,500 | 0 |
| Strawberry | 70,300 | 48,100 |
| Lettuce | 9,700 | 34,200 |
| Cabbage | 400 | 159,800 |
| Other vegetables | 96,300 | 113,400 |
| *Other horticulture* | 4,900 | 0 |
| *Other output* | 633,000 | 49,600 |
| **Payments of costs and depreciation** | | |
| *Total paid costs and depreciation* | 2,343,200 | 432,00 |
| Specific costs | 405,700 | 146,200 |
| Fertilisers | 45,600 | 11,300 |
| Seeding and planting material | 171,700 | 73,300 |
| Crop protection agents | 43,100 | 18,600 |
| Energy | 582,700 | 12,500 |
| Electricity | 101,300 | 11,400 |
| Gas | 441,400 | 900 |
| Intangible assets | 0 | 600 |
| Tangible assets | 464,300 | 111,800 |
| Rent | 3,100 | 17,800 |
| Depreciation of buildings and greenhouses | 94,700 | 13,100 |
| Depreciation of machines and equipment | 145,200 | 31,600 |
| Fuel | 4,900 | 11,100 |
| Maintenance | 209,100 | 34,200 |
| Labour paid | 586,500 | 114,500 |
| Contractors | 135,100 | 10,600 |
| Finance costs | 45,900 | 11,500 |
| General costs | 122,900 | 24,400 |
| **Results** | | |
| *Family income from basic farm activity* | 475,500 | 123,100 |
| *Extraordinary profits/losses* | -6,200 | 100 |
| *Family farm income* | 451,200 | 123,100 |
| *Family farm income per unpaid a.w.u.* | 288,300 | 78,400 |

| Variables | Horticulture under glass: vegetable farms | Open field vegetable farms |
|---|---|---|
| Number of sampled holdings | | |
| Area | | |
| Utilised agricultural area (ha) | 6.2 | 21.9 |
| Area under glass (are) | 494 | |
| Number of livestock | | |
| Holding size and intensity | | |
| Standard Output (SO) (1,000 euro) | 2,048 | 522 |
| SO per ha (1,000 euro) | 331.22 | 23.88 |
| Socio/economic data | | |
| Annual work units (a.w.u.) (number) | 18.55 | 5.22 |
| of which non paid a.w.u. (number) | 1.57 | 1.57 |

Source: Agrimatie.nl.

## 3.3 Trade

The greenhouse horticultural sector is heavily dependent on exports. More than 70% of the greenhouses vegetable products are exported to other European countries.

The Dutch (greenhouse) horticultural complex is known because of its economic performance (see Figure 3.4). Figure 3.9 shows about the sizes and dimensions of fruits and vegetables products. The economic importance of the horticultural is not only depending on their domestic production, but even more on their trading activities (see import figures).

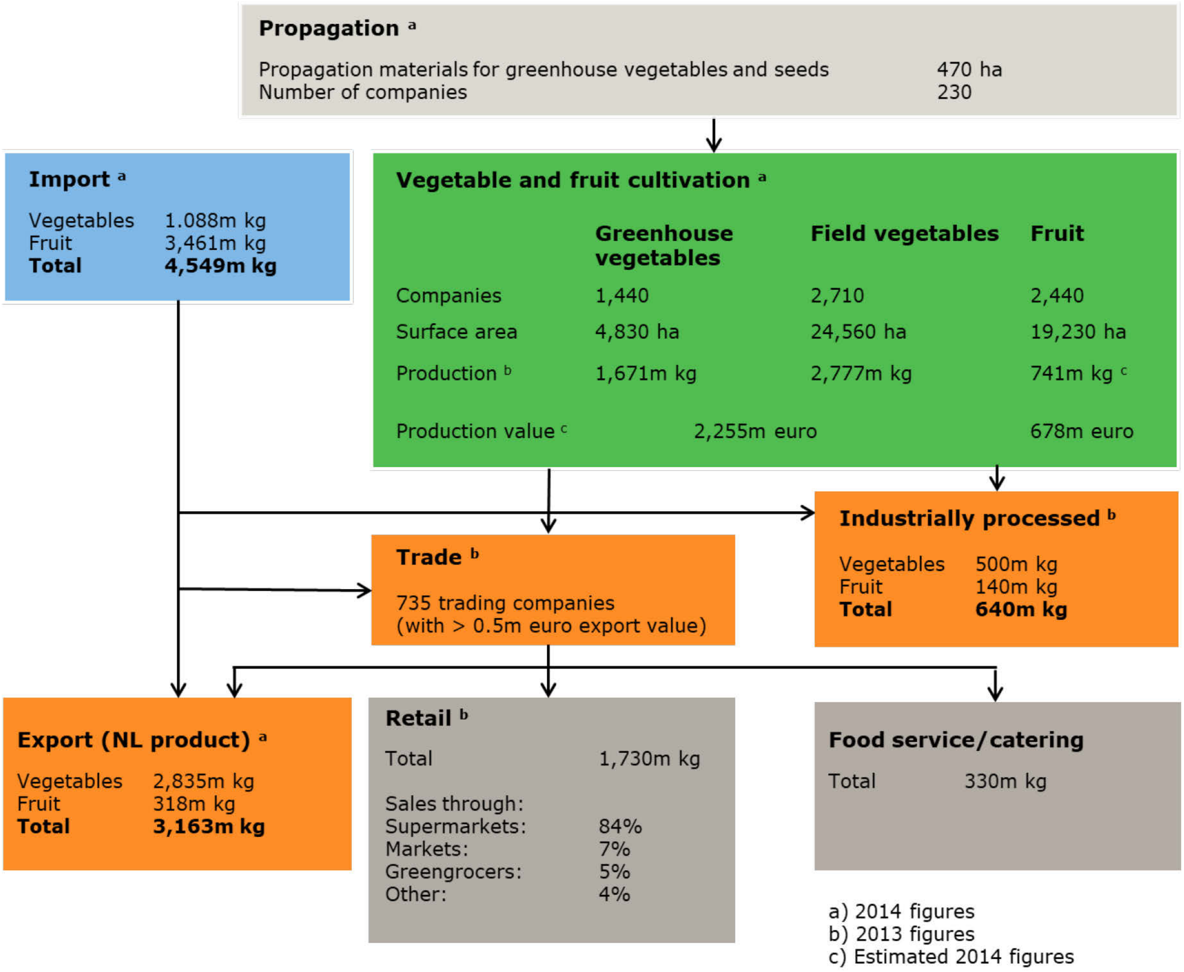


***Figure 3.9*** *Schematic overview of the Dutch vegetable and fruit supply chain, 2014*
*Sources: Eurostat, KCB, CBS, Frugi Venta, GroentenFruit Huis, Wageningen Economic Research.*

Although the figures are from 2014 in general the same picture can be expected in 2019, with the exception that the number of holdings and companies have decreased.

The USA is ranked seventh as export destination of Dutch agricultural goods and agriculture-related goods (Jukema et al., 2020). The export of Dutch agricultural goods and agriculture-related goods to the USA is illustrated in Table 3.2. With respect to agriculture-related goods the main export goods are machines for the processing industry and machines for agricultural production. Far behind this are fertilisers, greenhouse materials and pesticides.

**Table 3.2** *Export of Dutch agricultural goods and agriculture-related goods to the USA in 2018, x 1,000 euros)*

| | Total euros | % | | Total euros | % |
|---|---|---|---|---|---|
| All agricultural goods | 2,533,252 | 81.0 | All agriculture-related goods | 594,122 | 19.0 |
| *By product group (2-digit GN code)* | | % | *By product group* | | % |
| GN-01 Living animals | 232,644 | 9.2 | Fertilisers | 48,542 | 8.2 |
| GN-02 Meat | 30,916 | 1.2 | Crop protection agents | 28,961 | 4.9 |
| GN-03 Fish and seafood | 91,521 | 3.6 | Agricultural machinery | 219,785 | 37.0 |
| GN-04 Dairy and eggs | 83,886 | 3.3 | Tractors and agricultural trailers | 5,403 | 0.9 |
| GN-05 Other animal-source products | 9,221 | 0.4 | Agricultural tools | 1,443 | 0.2 |
| GN-06 Floriculture | 232,925 | 9.2 | Machinery for the food industry | 243,311 | 41.0 |
| GN-07 Vegetables | 123,857 | 4.9 | Animal vaccines | 52 | 0.0 |
| GN-08 Fruit | 4,164 | 0.2 | Agricultural dryers | 279 | 0.0 |
| GN-09 Coffee, tea, spices | 17,330 | 0.7 | Greenhouse materials | 44,788 | 7.5 |
| GN-10 Grains | 577 | 0.0 | Stable fittings | 208 | 0.0 |
| GN-11 Flour, malt and starch | 34,154 | 1.3 | Irrigation sprinkler systems | 1,350 | 0.2 |
| GN-12 Oleaginous seeds and fruits | 155,019 | 6.1 | | | 100.0 |
| GN-13 Saps | 43,446 | 1.7 | All agriculture goods and agriculture-related goods | 3,127,373 | |
| GN-14 Weaving materials (e.g. bamboo, reeds) | 2,593 | 0.1 | | | |
| GN-15 Natural fats and oils | 39,092 | 1.5 | | | |
| GN-16 Prepared meat and fish | 1,700 | 0.1 | | | |
| GN-17 Sugar and sugar products | 50,803 | 2.0 | | | |
| GN-18 Cocoa and cocoa products | 160,765 | 6.3 | | | |
| GN-19 Processed grain, flour and milk products | 47,134 | 1.9 | | | |
| GN-20 Processed vegetables and fruits | 82,077 | 3.2 | | | |
| GN-21 Other foods | 119,213 | 4.7 | | | |
| GN-22 Drinks | 773,790 | 30.5 | | | |
| GN-23 Food industry byproducts, animal feed | 60,543 | 2.4 | | | |
| GN-24 Tobacco and tobacco products | 13,490 | 0.5 | | | |
| GN-X HX. Other primary and secondary agriculture | 122,393 | 4.8 | | | |
| | | 100.0 | | | |

Source: Dutch Central Bureau of Statistics 2020, processed by WEcR.

As mentioned in Section 3.2 and Figure 3.4 the production sector and the supplying industry within the outdoor horticultural and greenhouse horticultural complex, are the main contributors to the economy. The distribution and especially the processing industry are of minor relevance.

*COVID-19 and economic impact*

The outbreak of COVID-19 in February 2020 in Wuhan (China) has hit the world with very strong limitations in the transportation of people and goods due to government decisions. Also The Dutch greenhouse horticultural complex has faced this severely, in particular the ornamental complex. The corona crisis shows that The Netherlands as export country of agricultural products is in such situations vulnerable. It also makes clear that imports of essential food and goods in countries can hamper and will cause shortage of these food and goods for a short or longer period.

From this point of view, a shortage of fresh fruit and vegetables can be very critical and raises the question whether a more substantial part of these products should be self-produced (higher degree of self-sufficiency). The trend towards more self-sufficiency in fresh food is already underway in view of the increasing worldwide interest in greenhouse horticulture.

## 3.4 Sustainability performance

*Introduction*
Sustainability in Dutch agriculture can be expressed in many ways. The most ‘extreme’ situation is production, according to the European regulations, by means of the label organic. The term ‘organic’ on the packaging of a product sold in Europe indicates that it complies with European regulations for organic products. Organic cultivation means that no chemicals are applied for crop protection and fertilisation and that the plants grow in (bare) soil and not in artificial growing media.

The number of organic cultivation in greenhouses is small (in share 2.9%), also in comparison to outdoor vegetable farms (4.5%) (agrimatie.nl).

In the USA organic farming has a different meaning. According to the Consumer Brochure, USDA National Organic Program 2007

> ‘organic food is produced by farmers who emphasise the use of renewable resources and the conservation of soil and water to enhance environmental quality for future generations. Organic food is produced without using most conventional pesticides; fertilisers made with synthetic ingredients or sewage sludge; bioengineering; or ionising radiation. Before a product can be labelled “organic” a Government-approved certifier inspects the farm where the food is grown to make sure the farmer is following all the rules necessary to meet USDA organic standards. Companies that handle or process organic food before it gets to your local supermarket or restaurant must be certified, too.’

In this view a minimum use of conventional chemical pesticides and fertilisers and cultivation in artificial substrates is allowed. Following the USDA definition more Dutch greenhouse horticultural products would receive the label organic. In fact, some Dutch greenhouse horticultural products are already being exported with the label organic to the USA.

*Energy*
The main environmental impact of greenhouse horticulture is the use of energy for heating, cooling, artificial lighting and/or $CO_2$ application. In Figure 3.10 the energy consumption of greenhouse vegetable farms and outdoor vegetable farms is shown.

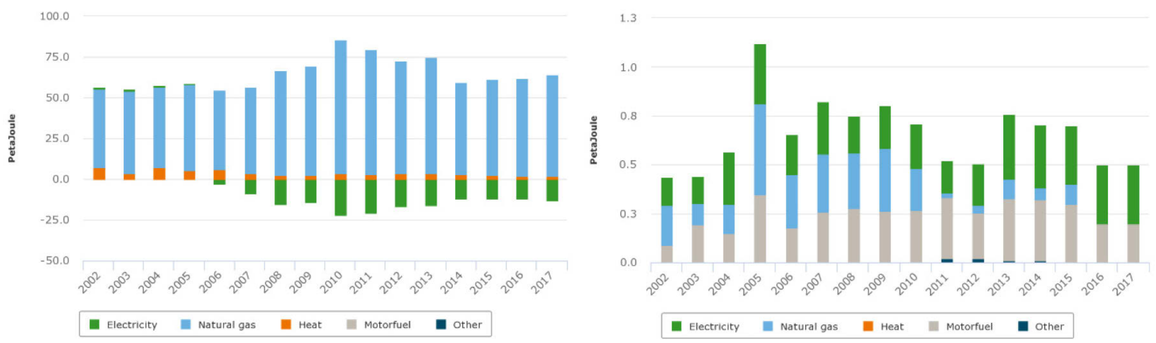


***Figure 3.10*** *Average energy use on greenhouse vegetable and outdoor vegetable farms (agrimatie.nl)*

Figure 3.10 shows the very large difference in energy consumption of the two vegetable sectors. The main energy supplier in greenhouse horticulture is natural gas. As a result also the $CO_2$ emission of high-tech greenhouse vegetable production is on a higher level than of outdoor vegetable cultivation. In comparison with outdoor vegetable farms, a substantial number of greenhouse vegetable farms also supply electricity from solar panels to the public grid as a result of the application of combined heat and power (CHP) installations. These CHP installations produce heat, power and $CO_2$. In some cases electricity is sold (fully) to the public grid.

*Water and nutrients*
With respect to emissions of water and nutrients the water consumption of greenhouse vegetable farms is filled in more and more by rainwater. Rainwater has a more suitable (higher) quality than tap water, surface and well water. This is also caused by the higher water use efficiency of greenhouse vegetable production as a result of recirculation and purification of the process water. Greenhouse horticulture enables to achieve a high water use efficiency, especially in closed growing systems (see Figure 3.11).

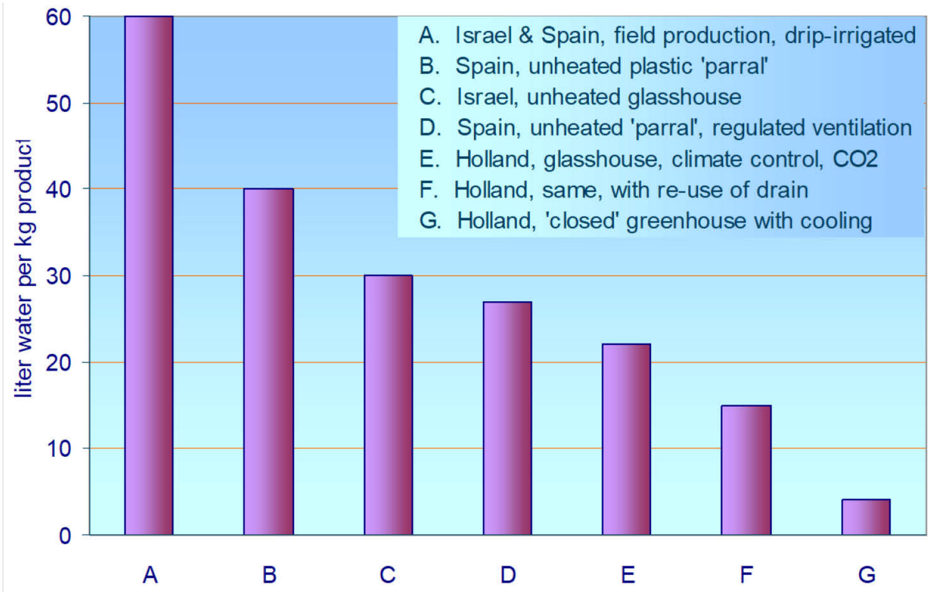


***Figure 3.11*** *Water use (litres per kg tomato) of tomato production in various growing systems in different countries. The technology content increases rightwards*
*Source: Stanghellini, C., 2014. Horticultural production in greenhouses: efficient use of water. Acta Horticulturae, 1034. p. 25-32.*

Figure 3.11 shows that the more technology is being used in growing systems, the more efficient the water use. Instead of 60 litres per kg of fresh tomatoes in outdoor cultivation only 6 litres per kg of fresh tomatoes is needed in closed growing systems through recovering of drain water and transpiration water. In some regions of the Netherlands well water is available, mostly in combination of reversed osmosis (desalination of water). In other regions, rainwater is stored in the subsurface for use in periods of little rain.

With regard to fertiliser consumption, the fertiliser costs in 2018 on an average greenhouse vegetable farm of about 5 ha are almost 4 times higher than on an average open field vegetable farm of about 22 ha) (see Table 3.1). The higher fertiliser costs in greenhouse vegetables are explained by both the higher fertiliser consumption as well as the higher costs of liquid fertilisers. A main advantage of protected cultivation - especially hydroponics - is the low(er) emission of water and nutrients to subsoil in comparison to outdoor cultivation in the soil. Only in soil cultures in greenhouses like lettuce, leafy vegetables and radish diffuse emission will occur, because the drain water cannot easily be recovered.

*Crop protection*
With respect to crop protection, greenhouse vegetable farms nowadays apply biological control as a starting point for integrated pest management (IPM). Only in some circumstances, for instance when there are new diseases such as the current Tomato Brown Rugose Fruit Virus (ToBRFV) and there is high disease pressure, chemicals will be used to correct. Most chemicals can be applied in combination with biological control.

In outdoor vegetable production more biological control and other methods are being used to control weeds, pests and diseases. The number and share of outdoor organic farms (according to EU standards) are higher than in protected cultivation (agrimatie.nl).

Unfortunately, no comparison can be made between greenhouse vegetables and outdoor vegetables with respect to the physical use of chemical crop protection agents. From Table 3.1, it can be seen that the costs of crop protection in greenhouse vegetable production are more than twice as high as in outdoor vegetable production. This seems to indicate that the use of chemicals for crop protection are at least higher than in outdoor cultivation.

# 4 Vegetable production in the USA

## 4.1 Domestic production

### 4.1.1 Acreage

Cultivation of vegetables in the USA mainly takes place uncovered. There is some cultivation in greenhouses, but this is negligible in terms of area. Cultivation in tunnels takes place more frequently, but statistics are not distinguished separately. The most recent figure about the protected cultivation of vegetables in the USA is 1,045 ha in 2017, which includes cut flowers and ornamentals and with glasshouses in the minority compared with plastic tunnels (USDA, 2019).

The main states for growing vegetables in the USA are Florida and California. Table 4.1 shows the cultivation area of vegetables in the USA. In terms of development of production area, there are fluctuations between the years. It seems that there has been a tendency to decrease the total area (protected and outdoor cultivation). Growing under unprotected conditions means that the cultivation, harvest and sales season depends largely on the climatic conditions.

***Table 4.1*** *Area protected and outdoor cultivation (ha harvested) of tomatoes (fresh), cucumber/pickle, and bell pepper in the USA, 2014-2019 a)*

| | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 |
|---|---|---|---|---|---|---|
| Cucumber and Pickle | | | 46,418 | 47,430 | 44,800 | 40,793 |
| Tomato | | | 141,273 | 125,656 | 130,270 | 110,764 |
| Bell pepper | 17,806 | 16,552 | 17,928 | 17,078 | 16,066 | 15,500 |
| Total | | | 205,619 | 190,164 | 191,136 | 167,057 |

a) Gherkin and cucumber are not separated in statistics.

Source: United States Department of Agriculture (USDA 2019).

### 4.1.2 Growing conditions

Growing conditions are mainly determined by the climate and natural resources. In this section, the amount of radiation, the temperature and the relative humidity will be discussed In later sections, attention will be paid to the availability of energy and $CO_2$, the substrate, the fertiliser supply, the availability and quality of water.

In general, the most limiting factor is the most determining factor.

***Table 4.2*** *Average radiation sum (kWh/m$^2$) per month for the different states in the USA and for comparison, the Netherlands*

| | Month | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | Total |
| Florida | 100 | 118 | 153 | 175 | 193 | 174 | 173 | 168 | 148 | 137 | 108 | 95 | 1,742 |
| California | 85 | 112 | 148 | 195 | 219 | 237 | 227 | 215 | 180 | 131 | 95 | 74 | 1,918 |
| Kentucky | 62 | 81 | 111 | 149 | 170 | 181 | 185 | 172 | 139 | 103 | 76 | 53 | 1,482 |
| New Hampshire | 59 | 85 | 111 | 152 | 166 | 180 | 186 | 168 | 136 | 94 | 67 | 49 | 1,453 |
| Netherlands | 20 | 40 | 82 | 123 | 142 | 151 | 149 | 135 | 96 | 53 | 26 | 15 | 1,032 |

Source: NASA 2020.

With respect to climate average figures are discussed of natural radiation, temperature and humidity. It has to be mentioned that average figures are useful, but that the distribution is also relevant especially of minimum and maximum levels.

*Natural radiation*
There are large differences in light sum per state. This is illustrated in Table 4.2. Regarding the light sum in the summer in the Netherlands it can be concluded that above 150 kWh/$m^2$ light is not a limiting factor.

The natural quantity of solar radiation is very important when growing in greenhouses as a source for growth and heating. From that perspective the regions Midwest and East Coast and California have a much higher quantity of total radiation sum than the Netherlands, which is favourable for production. Under Dutch circumstances, extra light in vegetable production will not increase production from 1 May. This is above 4.6 kWh/$m^2$ per 24 hours. In bell pepper production, too much direct radiation can even lead to burn marks (J. Janse, crop specialist WPR/BU Greenhouse Horticulture in interview with author).

Artificial lighting (assimilation lamps) can be considered when natural radiation is insufficient to produce the desired quality and/or to lengthen the production season with the aim to earn back the (high) investments. This decision will be mainly determined by the targeted market segment (of high value product) and/or climate conditions (with shortage of natural light in the winter period). Given the natural light radiation level in California, artificial lighting of vegetable cultures seems not always to be necessary unless high value products are going to be produced.

*Temperature*
Most vegetables grow well at a temperature of 15 to 25°C. The most optimal temperature is an outside temperature of 21 to 24°C (J. Janse, crop specialist WPR/BU Greenhouse Horticulture in interview with author). Extreme inside temperatures are very harmful to crops or fruits, resulting in a decrease of production. In greenhouses the temperature can be controlled well, but especially when it is extremely hot outside (> 30°C), the temperature inside the greenhouses can rise too much. Depending on the temperature level and its duration, temperatures higher than 25°C will have a negative effect on production. In tomato growing, higher temperatures will lead to fruit setting problems.

Outside temperatures above 40°C are problematic for cultivating vegetables in greenhouses. The use of a fogging installation can be useful, especially in case of cucumber growing, but its effect is limited (J. Janse (crop specialist WPR/BU Greenhouse Horticulture) in interview with author).

Low outside temperatures have little effect on growing vegetables in greenhouses, because heating will compensate this. Table 4.3 shows the average temperatures per month per state.

***Table 4.3*** *The average temperature per month for four states of the USA (C°)*

| | Month | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Jan. | Febr. | Mar. | Apr. | May | Jun. | Jul. | Aug. | Sep. | Oct. | Nov. | Dec. |
| Florida | 14.2 | 15.2 | 10.1 | 12.6 | 16.0 | 19.7 | 23.1 | 22.8 | 20.2 | 16.1 | 10.6 | 7.0 |
| California | 6.9 | 8.8 | 23.5 | 24.8 | 25.8 | 26.8 | 27.3 | 27.4 | 26.9 | 26.2 | 23.9 | 22.7 |
| Kentucky | 0.3 | 2.3 | 7.6 | 13.0 | 17.7 | 22.1 | 24.2 | 23.5 | 20.0 | 13.7 | 8.0 | 2.6 |
| New Hampshire | -8.1 | -6.8 | -1.2 | 5.4 | 11.9 | 16.8 | 19.5 | 18.2 | 13.7 | 7.8 | 2.0 | -5.2 |

Source: www.worldclim.org.

It is clear from the monthly temperatures that cultivating in greenhouses in Florida and California will not cost much energy to heat greenhouses. The number of months in California with a low average temperature is very limited. On the other hand, the number of months with high average temperatures is higher in California in particular. This will make it necessary to implement cooling in the greenhouse, which is more expensive than heating. This is different from Kentucky and New

Hampshire which do not have to be a disadvantage due to climate control. The chance of days with a temperature above 30ºC is low in Kentucky and New Hampshire, which is favourable for the production of vegetables.

*Relative humidity*

The optimum relative humidity (RH) for growing vegetables is between 70 and 90% (www.worldclim.org). This can usually be achieved in greenhouses. In the event of a prolonged drought outside the greenhouse it can be problematic to keep the RH at the desired level. In extremely humid conditions and lower temperatures heating can keep the RH at a lower level. American weather statistics show that the RH does not cause problems except in the extremely dry areas. Relative humidity above 95% does increase the chance of quality diseases like botrytis and has a detrimental effect on fruit setting of tomatoes.

### 4.1.3 Availability of energy and $CO_2$

In some periods of the year, especially during winter, the outside temperature can be very low or too low. In those situations heating the greenhouse will keep the temperature at the desired level. It is important that energy carriers such as oil, natural gas or propene, which are indispensable for greenhouse production, are also available under extreme circumstances.

One of the building elements of growth is $CO_2$ and this can be the growth limiting factor under high radiation conditions. $CO_2$ can be applied during cultivation in greenhouses, either in the form of flue gases (from the boiler) or in the form of pure $CO_2$ that is purchased. It can be assumed that the $CO_2$ supply during cultivation in greenhouses in the USA is not a problem.

### 4.1.4 Growing media

In outdoor cultivation, vegetables are grown in the open field. The soil type is very important for optimal growth. Growers have the option of applying crop rotation. When cultivating in greenhouses, growing media are even more important. To prevent soil related pests and diseases, such as nematodes and fungi, growers will shift from soil to artificial substrate. Different growing media will be available, such as rockwool, cocopeat, vulcanic material, etc. An additional advantage of cultivation on substrate is that the fertilisers can be supplied as needed and that drain water can be recycled.

### 4.1.5 Fertilisers

When cultivation on substrates, growers will have to use liquid fertilisers in order to realise the desired recipe. Besides, fertigation can then be done more specific to the needs of the crop. The emission of nutrients will be reduced by reusing the drain water in substrate cultures resulting in a higher input efficiency. This will further improve when the process water will be purified to prevent the spread of diseases within the growing system.

### 4.1.6 Availability of water and water quality

Another important growth factor is the availability of water. Rainwater has mostly the best quality for vegetable growing, regardless of whether it is cultivation in greenhouses or cultivation outside. When cultivating in greenhouses and crops grow along a rope and have a lot of leaf surface, the water consumption is determined by the crop evaporation. The quality of the water supply depends on how often the drain water can be recycled. Rainwater that falls on greenhouses has to be collected in a water basin. Depending on the content of the basin in relation to the surface of greenhouses, water from other sources probably has to be used during dry periods. It is possible to invest in a reverse osmosis system to improve the water quality (desalination). Concerning the availability of rainwater also the total rainfall and the distribution of the rainfall over a year are important. This is shown in Table 4.4 for four American states.

**Table 4.4** *Average rainfall (mm per cm²) per month for four states of the USA*

| | Month | | | | | | | | | | | | Yearly sum |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | |
| Florida | 72 | 86 | 92 | 64 | 100 | 166 | 183 | 182 | 157 | 79 | 57 | 65 | 1,303 |
| California | 82 | 71 | 66 | 34 | 11 | 4 | 5 | 10 | 12 | 21 | 58 | 66 | 440 |
| Kentucky | 88 | 95 | 120 | 109 | 121 | 102 | 121 | 97 | 90 | 76 | 104 | 109 | 1,232 |
| New Hampshire | 80 | 77 | 85 | 91 | 98 | 97 | 96 | 102 | 87 | 94 | 109 | 97 | 1,113 |

Source: www.worldclim.org. Note: The yearly rainfall in The Netherlands is 700-800 mm per cm².

Table 4.4 shows that the yearly rainfall in the selected USA states is higher or much higher than in the Netherlands with the exception of California. Because of the expected rainfall, per unit of greenhouse area more water basin content will be needed. The distribution of rainfall over a year is just as important for the basin content to be installed.

Another factor is the competition for water by other water-consuming sectors, such as industry and housing. The effect of competition will of course differ per state or region in the USA. In most cases worldwide, agriculture is the last in line when water shortages occur.

Crop evaporation will be higher in Florida and California than in Kentucky, due to the higher levels of natural radiation. This requires additional basin capacity especially in California. For these reasons, the basin volume to be installed in California should be considerably larger than in Kentucky and New Hampshire. The rainfall in New Hampshire is characterised by its regularity. Nevertheless, in all states also in quality comparable water might be necessary to complement the supply of rainwater, such as subsoil water or water wells.

### 4.1.7 Planting material

For optimal cultivation, it is important to start from high-quality planting material which is produced by specialised companies. Most important aspect is the availability of the best suitable varieties. Tomato plants of high quality has to be grafted to become resistant against soil diseases (J. Janse (crop specialist WPR/BU Greenhouse Horticulture) in interview with author). Because of long distances and transport by airfreight, planting material from the Netherlands can involve relatively high costs. For vegetables mostly seeds will be used and transported over long distances, because of their low volume. The extent to which high quality planting material is available and at what costs, is not clear from literature, but is surely a point of attention. Several Dutch seed and breeding companies have their own nursery/democentre and distributor in the USA, such as RijkZwaan, Enza Zaden and Bejo.

### 4.1.8 Production and cultivation system

The type of greenhouse on the one hand depends on the climate conditions and its extremes (wind, snow, etc.) and on the other hand on the market segments of vegetables the producers are focus on. Climates with higher radiation and higher temperatures are more favourable for plastic greenhouses (Vanthoor et al., 2012). In mild climates with moderate radiation and temperatures, such as the Netherlands, glasshouses are more common.

For producers targeting high-end markets, high-tech greenhouses - enabling cultivation to be be better controlled - are more suitable for achieving higher product quality and a better sustainability (higher input efficiencies).

High-tech greenhouse production implies that negative external effects on crop growth and development can be reduced to a large extent. Cultivation can then be better managed by means of climate control, integrated pest management or biological control, water & fertiliser management and cultivation and labour planning.

For fruit vegetable cultivation in greenhouses, it is recommended to set up with a high wire system as is widely used in the Netherlands. Cultivation takes place on rockwool slabs in gutters and water supply is done by drip-irrigation. Reuse of process water will be combined with purification.

### 4.1.9 Climate change

Climate change will within fifty years result in an increase of the temperature and it will become a source of tension with respect to water availability (National Geographic, 2020). The increasing need of drinking water will probably deplete freshwater supplies. Also climate extremes will occur more frequently, such as heavy rainfall, long drought period, hurricanes, etc. As an example, the wildfire in Ventura, California, in 2017, destroyed an area of 1,130 $km^2$. Due to the climate change it is expected that the number of wildfires will increase in California (National Geographic, 2020).

Besides the local or regional climate situation and other biophysical conditions (soil, infrastructure, urbanisation) also climate change should be considered in the search for potential locations for greenhouse horticultural production.

## 4.2 Domestic consumption, production and imports of fresh vegetables

Domestic consumption of fresh vegetables, such as tomatoes, cucumbers and bell peppers in the USA is difficult to find and is derived from production, import and export (see Table 4.5).

***Table 4.5*** *Production, import and consumption of fresh vegetables and the consumption of vegetables per capita (kg/year) of fresh tomatoes, cucumbers and bell peppers in the most recent years in the USA*

| | Production (million kg) | Import (million kg) | Total supply (million kg) | Export (million kg) | Available = consumption (million kg) | Consumption per capita (kg/year) a) |
|---|---|---|---|---|---|---|
| | Cucumber | | | | | |
| 2018 | 252 | 937 | 1,188 | 12 | 1,176 | 3,6 |
| 2019 | 233 | 968 | 1,201 | 14 | 1,187 | 3.6 |
| | Bell Pepper and Pepper | | | | | |
| 2018 | 580 | 1,109 | 1,689 | 47 | 1,642 | 5.0 |
| 2019 | 588 | 1,133 | 1,722 | 47 | 1,675 | 5.1 |
| | Tomato | | | | | |
| 2018 | 1,227 | 1,841 | 3,068 | 82 | 2,986 | 9,1 |
| 2019 | 1,239 | 1,847 | 3,085 | 78 | 3,007 | 9,1 |

Consumption is calculated from supply minus export.

Source: USDA, Vegetable and pulses yearbook data 2020. Statista 2019; C. Miller 2019; H. Garming, 2014.

Table 4.5 shows also the consumption per capita per year of fresh tomatoes, cucumber and bell peppers in the USA, which remained stable between 2014 and 2018. In the Netherlands, the consumption of fresh tomato is 7.4 kg, of cucumber 3.1 kg and of bell pepper 1.4 kg per capita per year (Wat eet Nederland.nl, 2020). No distinction is available by different product types and/or colours.

## 4.3 Supply of vegetables

The sales of vegetables in the USA is arranged by contracts that are concluded months before actual deliveries (traders in interviews with author). Within the crops of tomato, cucumber and pepper, there is a considerable degree of product differentiation in the form of different shapes and colors. Statistical data on the production per type are lacking (see Table 4.6). This should be taken into account in newly to be established greenhouse vegetable companies, depending on what the wishes of potential customers are.

The production and import of fresh vegetables determine the potential supply and are mentioned in Table 4.5. The imports contribute largely to the total supply of vegetables in the USA. A small quantity is exported to other countries. The USA is highly dependent on Mexico and, to a lesser extent, Canada, for its fresh vegetable imports. The import tariffs of vegetables for Mexico will affect the quantum of imported vegetables. In 2019 the USA government threatened Mexico with increasing import tariffs, unless Mexico would take border actions to reduce the surge of migration into the United States. The first announcements to increase import tariffs for Mexico was cancelled at the last moment.[1]

Besides fresh vegetable consumption also processed vegetables consumption is relevant (see Table 4.6).

***Table 4.6*** *Production, import, export and consumption of processed cucumbers and tomatoes in the USA*

| Year | Domestic production | Imports | Beginning stocks | Supply total | Exports | Ending stocks | Available | Consumption per capita |
|---|---|---|---|---|---|---|---|---|
| | Cucumber million kg (Pickles) | | | | | | | Kg |
| 2016 | 452 | 40 | 38 | 529 | 46 | 48 | 436 | 1,35 |
| 2017 | 624 | 42 | 48 | 534 | 49 | 129 | 536 | 1,65 |
| 2018 | 442 | 42 | 129 | 613 | 49 | 75 | 491 | 1,50 |
| 2019 | 513 | 44 | 75 | 632 | 54 | 72 | 506 | 1,54 |
| | Tomato million kg | | | | | | | Kg |
| 2016 | 11,854 | 647 | 11,049 | 23,545 | 3,576 | 11,082 | 8,892 | 27,52 |
| 2017 | 9,859 | 676 | 11,081 | 21,617 | 2,984 | 1,0,162 | 8,471 | 26,05 |
| 2018 | 11,513 | 709 | 10,162 | 22,384 | 2,795 | 9934 | 9,655 | 29,51 |
| 2019 | 10,696 | 769 | 9,934 | 21,399 | 2,606 | 8,721 | 10,073 | 30,60 |

Source: SanduProcessed (USDA, 2020).

Vegetables produced for the processing industry are open field and are of less quality than the produce for fresh consumption. Greenhouses are intended to produce high-quality vegetables for the fresh market.

# 4.4 USA domestic market competition

In order to guarantee their sales, greenhouse vegetable companies in the USA have arranged contracts with retailers. Current consumption is partly covered by domestic production. Based on value this was in 2019 for cucumber 16,5% and for bell pepper 25,3%. For fresh and processed tomatoes together, this is 43% (USDA, 2019).

Because this mainly concerns outdoor crops, it concerns sales in the summer period. In the rest of the year, the demand for vegetables is met by imports. This is also the period when production from greenhouses mainly has added value.

[1] https://www.nytimes.com/2019/06/08/us/politics/trump-mexico-deal-tariffs.html

## 4.5 Cost price components

The cost price defined as the costs per product unit, together with the product quality, are the most important competition aspects. Quality includes besides the internal and external quality and longer shelf life also the ability to deliver on time. Short distances to sales markets offer advantages in view of transport costs, which are part of the cost price, and from the point of view of environmental footprint.

The main cost items for vegetable cultivation under glass are energy, depreciation of investment and labour. When artificial lighting needs to be applied, this will increase the costs of energy significantly.

In the USA, a minimum wage of 6.59 euros per hour (year 2020) applies. It is the lower limit for the whole of the USA; individual states can deviate from this. For example, Florida has a minimum wage of 7.32 euros per hour and California of 8.18 euros per hour (see Table 4.8). For comparison, the Netherlands has a minimum wage of 9.54 euros per hour. Due to income inequality, the average wage in the USA is 13% higher than in the Netherlands (OECD, 2019).

***Table 4.8*** *Minimum wages per state and prices for natural gas per state (euros per hour and euros per $m^3$ industrial price)*

| | California | Kentucky | Florida | New Hampshire |
|---|---|---|---|---|
| Minimum wage per hour in 2020 | 11.81 | 6.59 | 7.78 | 6.59 |
| Price of natural gas (2019) | 0.24 | 0.12 | 0.19 | 0.25 |

Source Minimum wages: Zakelijk banen; Minimum loon Verenigde Staten, 2020.

Source Energy prices: US Energy Information Administration, 2019.

The price of natural gas differs per state. The energy costs will be the lowest when the energy price in combination with temperatures are the most favourable.

An estimation how this relates to the costs incurred for import/country of origin will be carried out in a different study. The fact is that the labour costs of vegetables of Mexican origin will be much lower, as will the cost of energy. The costs of transport of imports from Mexico or Canada will be probably higher.

## 4.6 Availability of labour

Certainly in a state such as Kentucky, with high unemployment (U.S. Bureau of Labor Statistics, 2019) unskilled and skilled labour (on other fields) is sufficiently available to carry out cultivation work. Skilled middle management is also a prerequisite for healthy business operations, but may not be sufficiently available.

The unemployment rate in the USA had since 2015 been declining steadily towards 3.5% in February 2020, just before the corona virus outbreak in March 2020 (see Figure 4.1).

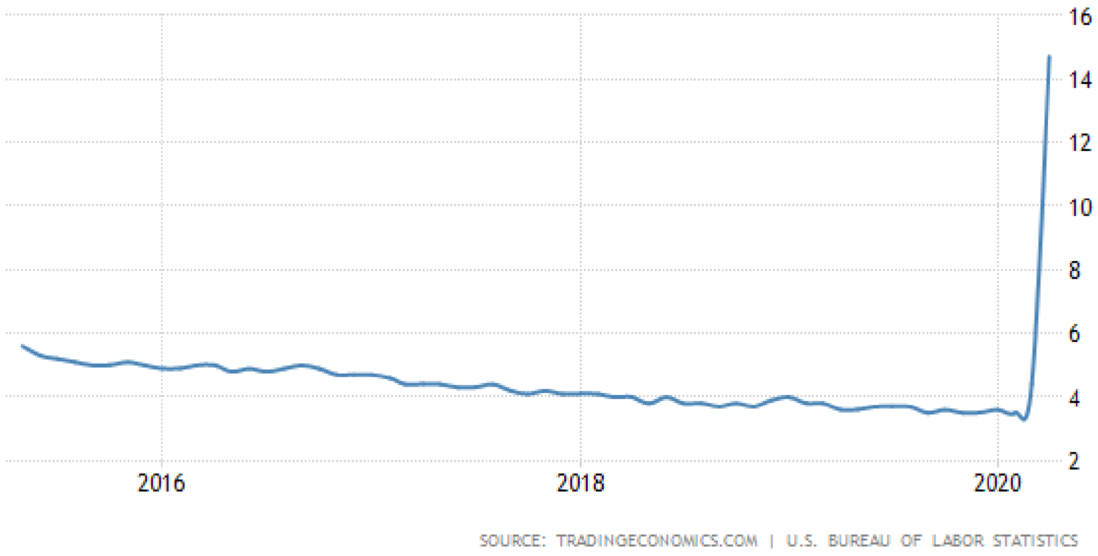


***Figure 4.1*** *Unemployment rate (%) in the USA since 2015 (last 5 years)*
*Source: Tradingseconomics.com; U.S. Bureau of Labor Statistics.*

Unemployment rates differ per state depending on various reasons (see Table 4.9). As the table shows, California, Kentucky and West Virginia have a high unemployment rate in comparison with other states such as Kansas, New Hampshire and South Carolina. An important factor will be if there are other sectors which offer employment for labour force and compete with the labour need of the agricultural sector.

***Table 4.9*** *Unemployment rate (%) in the USA by state in March 2020*

| State | June 2020(p) rate | Rank |
|---|---:|---:|
| Kentucky | 4.3 | 1 |
| Utah | 5.1 | 2 |
| Idaho | 5.6 | 3 |
| North Dakota | 6.1 | 4 |
| Maine | 6.6 | 5 |
| Oklahoma | 6.6 | 5 |
| Nebraska | 6.7 | 7 |
| Montana | 7.1 | 8 |
| South Dakota | 7.2 | 9 |
| Alabama | 7.5 | 10 |
| Kansas | 7.5 | 10 |
| Georgia | 7.6 | 12 |
| North Carolina | 7.6 | 12 |
| Wyoming | 7.6 | 12 |
| Missouri | 7.9 | 15 |
| Arkansas | 8.0 | 16 |
| Iowa | 8.0 | 16 |
| Maryland | 8.0 | 16 |
| New Mexico | 8.3 | 19 |
| Virginia | 8.4 | 20 |
| Wisconsin | 8.5 | 21 |
| District of Columbia | 8.6 | 22 |
| Minnesota | 8.6 | 22 |
| Texas | 8.6 | 22 |
| Mississippi | 8.7 | 25 |
| South Carolina | 8.7 | 25 |
| Vermont | 9.4 | 27 |

| State | June 2020(p) rate | Rank |
|---|---|---|
| Louisiana | 9.7 | 28 |
| Tennessee | 9.7 | 28 |
| Connecticut | 9.8 | 30 |
| Washington | 9.8 | 30 |
| Arizona | 10.0 | 32 |
| Florida | 10.4 | 33 |
| West Virginia | 10.4 | 33 |
| Colorado | 10.5 | 35 |
| Ohio | 10.9 | 36 |
| Indiana | 11.2 | 37 |
| Oregon | 11.2 | 37 |
| New Hampshire | 11.8 | 39 |
| Alaska | 12.4 | 40 |
| Rhode Island | 12.4 | 40 |
| Delaware | 12.5 | 42 |
| Pennsylvania | 13.0 | 43 |
| Hawaii | 13.9 | 44 |
| Illinois | 14.6 | 45 |
| Michigan | 14.8 | 46 |
| California | 14.9 | 47 |
| Nevada | 15.0 | 48 |
| New York | 15.7 | 49 |
| New Jersey | 16.6 | 50 |
| Massachusetts | 17.4 | 51 |

Footnotes
(p) Preliminary

Note: Rates shown are a percentage of the labor force. Data refer to place of residence. Estimates for the current month are subject to revision the following month.

Source: U.S. Bureau of Labor Statistics, May 2020.

The need of labour (in hours per ha) for greenhouse horticultural activities consists of more than 90% of cultivational handlings and almost 10% of management operations (Raaphorst and Benninga, 2019).

As mentioned before, the availability of skilled labour is a prerequisite. The question is whether this labour is available locally and regionally or whether labour migrants are needed to fill the shortage of labour supply.

# 5 Opportunities of high-tech greenhouses for the vegetable supply chain in the USA

## 5.1 Market

An important advantage of vegetables produced in greenhouses compared to uncovered/outdoor vegetables is that vegetables from greenhouses can be supplied for a much longer period, especially when artificial lighting is applied. Another important aspect is that vegetables from greenhouses have a much more consistent and higher quality. Without artificial lighting, opportunities for American vegetables lie especially during periods when e.g. American uncovered tomatoes are not on the market or product quality of tomatoes cultivated in greenhouses are much better. Vegetables grown in glasshouses are intended for the higher market and price segments because of their better quality. The same is the case with cucumbers and bell peppers grown in greenhouses.

In the USA, there is an increasing demand for locally produced vegetables (local for local), which is also the strategy for the coming years (Schneider, 2019).

## 5.2 Available suitable areas

One site is more suitable for establishing new greenhouses than another. This depends on many factors (Benninga et al., 2017). In view of biophysical properties, it is especially important that the location of sites is favourable in climate terms (solar radiation, temperature and rainfall) and as much as possible horizontal. Assuming that cultivation is carried out on an artificial substrate, the surface still has to be as free from stones as possible, because the surface has to be equalised.

Another aspect to consider is the infrastructure. In the first place this means access to roads, but also the presence of resources via a gas pipe, water and electricity pipes are part of this. The water supply benefits from sufficient rainfall, preferably spread over the year as much as possible (see also Section 3.1.6). As mentioned in Section 4.1.9, also climate change has to be considered, especially the increase in temperature and the availability of fresh water resources, and the occurrences of expected climate extremes.

## 5.3 Sustainability requirements

Fueled by public opinion, increasing requirements are placed on the sustainability of fresh vegetables. This is mostly regulated by private standards. Applied crop protection products are an important part of the sustainability of vegetables. Vegetables grown in greenhouses are exposed to less pest and disease pressure than if they were grown outdoors. Residues of chemical crop protection products on vegetables can affect public health negatively.

Vegetables grown in greenhouses have much greater energy demand than vegetables grown uncovered. In addition, there is an increasing demand for local produced organic vegetables (Schneider, 2019).

## 5.4 Investments in high-tech greenhouses

Investing in greenhouse production means that investments must also be made in greenhouse equipment (see Table 5.1 for a summary). This includes greenhouse structures, heating systems, cultivation systems, watering systems, climate control, fertilising unit and crop protection equipment. The assimilation lighting equipment has been added additionally. An overview of all investments and investment costs is presented in Appendix 1a, 1b and 1c for a 2 ha, 4 ha respectively 10 ha greenhouse.

***Table 5.1*** *Budget of total investments and depreciation and maintenance costs (1,000 euros), arising from investment in 2, 4 and 10 ha high-tech greenhouses a)*

| Farm setup | Area | Investment | Depreciation | Maintenance costs |
|---|---|---|---|---|
| Excluding artificial lighting | 2 ha | 5,000 | 400 | 83 |
| | 4 ha | 8,600 | 700 | 133 |
| | 10 ha | 14,400 | 1,200 | 200 |
| Including artificial lighting | 2 ha | 6,200 | 580 | 90 |
| | 4 ha | 10,900 | 1,030 | 140 |
| | 10 ha | 20,000 | 2,000 | 220 |

a) It is assumed that infrastructure needs no extra investments.

Source: Kwantitatieve Informatie voor de glastuinbouw 2019 (Raaphorst and Benninga, 2019).

## 5.5 Estimation of production potential and investments opportunities

*Expected yield in high-tech greenhouses*

The yield of tomatoes from different types of greenhouse structures will differ. In general, the more high-tech equipment is used, the better the cultivation can be controlled and the higher the yield will be. Besides the greenhouse structure, also the other biophysical factors, climate, soil and resources, determine the production in quantity and quality.

In low-tech, passive, plastic greenhouses the year-round yield of truss or vine tomatoes (medium size) is about 10-15 kg/m$^2$. In mid-tech, plastic, greenhouses the yield can increase to about 20-30 kg/m$^2$, while in high-tech, plastic or glass, greenhouses the yield can rise up to 40-70 kg/m$^2$, depending on the options to control the greenhouse climate. With artificial lighting in high-tech glasshouses the yield (of large size vine tomatoes) can go up to more than 90 kg/m$^2$ (Raaphorst and Benninga, 2019; Stanghellini et al., 2017).

From now on, only the high-tech greenhouse will be considered, excluding and including artificial lighting. As starting point it is assumed that a truss tomato yield in greenhouses without artificial lighting will be about 55 kg/m$^2$ (range 50-60 kg/m$^2$) in the Dutch climate. The radiation sum in the Midwest and the East Coast states and in California is much higher than in The Netherlands (see Table 4.2). From that perspective the tomato yield in high-tech greenhouse in the selected USA states can be set on an average of 65 kg/m$^2$ (range 60-70 kg/m$^2$). The starting point is a modern entrepreneurship.

The radiation sum in the states of the USA is higher than in the Netherlands. It is not clear whether artificial lighting in these states will be always very useful. These states are on the same latitude as the South of Spain, where artificial lighting is hardly to be found. With artificial lighting the yield can be improved, but at high radiation levels other growing factors, such as $CO_2$ application, water supply, crop protection and heating (in colder periods) are more critical or limiting.

For pepper the same explanation can be held, but peppers are less light dependent than tomatoes and cucumbers. For pepper yield (green/red) it is assumed that the yield in the USA states can reach at about 35 kg/m$^2$ (range 32-38 kg/m$^2$).

For cucumber (three cropping system) the yield in these USA states is estimated at 240 pieces/m$^2$ or 103 kg/m$^2$ (range 230-250 pieces/m$^2$ or 98.7-107.3 kg/m$^2$) (Raaphorst and Benninga, 2019).

*Potential greenhouse vegetable area*
The estimation of the potential greenhouse vegetable area has been done based on the imports of fresh vegetable products. The imports of tomatoes, peppers and cucumbers for the fresh market – mainly from Mexico and Canada - is 1,847 tonnes x 1,000, 1,133 tonnes x 1,000 respectively 968 tonnes x 1,000 (see Table 4.1). The import volumes are divided by the aforementioned expected yields in greenhouse cultivation to determine the area of additional vegetable production in the USA. This acreage should be able to substitute imports completely.

***Table 5.2*** *Calculated acreage of greenhouse tomatoes, peppers and cucumbers (ha)*

| | | Tomato | Pepper | Cucumber | |
|---|---|---|---|---|---|
| Imports | Tonnes x 1,000 | 1,856 | 1,147 | 944 | |
| | | | | | Total |
| Yield at Standard level | kg/m$^2$ | 65 | 35 | 103 | |
| Lower level | kg/m$^2$ | 58 | 30 | 93 | |
| Acreage at Standard level | ha | 2,842 | 3,277 | 917 | 7,018 |
| Lower level | ha | 3,194 | 3,823 | 1,015 | 8,002 |

In Table 5.2 the acreage of greenhouse tomatoes, peppers and cucumbers is calculated for 2,840-3,190, 3,275-3,825 and 915-1,015 ha, depending on the expected yield level.

*Potential investments in high-tech greenhouse establishments*
In Section 5.5, the investments per ha of high-tech greenhouses is given. Based on the investments for greenhouses without artificial lighting and the potential area of greenhouse vegetables, the total investments can be calculated (see Table 5.2).

The calculated total investments in high-tech greenhouses (see Table 5.3) amount to USD 3,875-4,345m, USD 4,415-5,150m and USD 1,280-1,420m for tomato, pepper and cucumber greenhouse production. The overall investment in greenhouses production is calculated at USD 9,575-10,915m. This is about 200 times the current export of greenhouse materials to the USA in 2018 (see Table 3.2).

***Table 5.3*** *Calculated total investments in high-tech greenhouses for tomatoes, peppers and cucumbers without application of artificial lighting a)*

| | | Tomato | Pepper | Cucumber | |
|---|---|---|---|---|---|
| Investment, excl. artificial lighting | Euro x 1,000/ha | 1,259 | 1,259 | 1,259 | |
| | USD x 1,000/ha | 1,364 | 1,364 | 1,364 | |
| | | Tomato | Pepper | Cucumber | Total |
| Total investments (at standard yield) | Euro x million | 3,577 | 4,075 | 1,183 | 8,835 |
| | USD x million | 3,876 | 4,416 | 1,282 | 9,573 |
| Total investments (at lower yield) | Euro x million | 4,009 | 4,754 | 1,310 | 10,073 |
| | USD x million | 4,344 | 5,152 | 1,420 | 10,915 |

a) The calculated investments are based on the imports of fresh vegetables into the USA and the expected level of yield (standard or lower).

Table 5.3 shows the potential investments when all imports of fresh vegetables would be substituted by domestic production in greenhouses.

*Share of investments opportunities for Dutch greenhouse suppliers*
The question is which share the Dutch greenhouses suppliers could obtain in the establishment of high-tech greenhouses in the USA. The Dutch greenhouse suppliers have a good reputation in building high-tech greenhouses, but there is a strong competition from greenhouse constructors of the USA and from other countries such Canada and Israel. A rough estimation is that about 5-10% of the calculated investments in high-tech greenhouses should be achievable for Dutch greenhouse suppliers (this is 10-20 times more than the export of greenhouse materials to the USA in 2018). This is strongly dependent on the price-quality relation and the services the Dutch companies can deliver. An important factor is that the offered greenhouse meets the needs of the customer and the market segment on which he focuses.

In the above text the focus is put on high-tech greenhouses. We have to realise that also a part of the greenhouse structures will be in between mid-tech and high-tech. Mid-tech greenhouses will contribute more to the need of commodities which are affordable for a large group of consumers. In a more detailed study this can be assessed based on specific information of the market segments of fresh vegetables (if available).

In addition, there is the existing greenhouse vegetable production area, which will be renewed in the short to longer term.

The potential establishments of (high-tech) greenhouses will also offer perspectives for Dutch suppliers of fertilisers and crop protection means. As is shown in Table 3.2 these are also agriculture-related goods, which have find their way to the USA. Also for these agriculture-related goods a 10-20 times higher export potential can be possibly reached.

## 5.6 Estimation of labour need

The opportunities for greenhouse horticulture establishments also provide employment. Based on the calculated acreage for greenhouse vegetable production in Table 5.2 an estimation is made about the labour need for cultivation and management activities (see Table 5.4). The basis for the cultivation and management need per individual crop is derived from ‘Kwantitatieve informatie voor de glastuinbouw 2019’ (Raaphorst and Benninga, 2019).

***Table 5.4*** *Estimated labour need (employment) for the calculated acreage of greenhouse horticulture establishments (tomatoes, peppers and cucumbers) (in hours x 1,000)*

| Acreage[1] | | | Tomato | Pepper | Cucumber | Total |
|---|---|---|---|---|---|---|
| | Standard yield | ha | 2,842 | 3,237 | 940 | 7,018 |
| | Lower yield | ha | 3,184 | 3,777 | 1,041 | 8,002 |
| Cultivation labour | | | | | | |
| | Standard yield | hours/ha | 8,500 | 6,100 | 9,300 | |
| | Lower yield | hours/ha | 7,600 | 5,500 | 8,800 | |
| Management labour | | hours/ha | 550 | 550 | 550 | |
| | | | | | | |
| Total cultivation labour | | | | | | |
| | Standard yield | hours*1,000 | 24,153 | 19,747 | 8,740 | 52,640 |
| | Lower yield | hours*1,000 | 24,202 | 20,772 | 9,160 | 54,133 |
| Total management labour | | | | | | |
| | Standard yield | hours*1,000 | 1,563 | 1,780 | 517 | 3,860 |
| | Lower yield | hours*1,000 | 1,751 | 2,077 | 572 | 4,401 |
| Total labour need | | | | | | |
| | Standard yield | hours*1000 | 25,716 | 21,527 | 9,257 | 56,500 |
| | Lower yield | hours*1000 | 25,954 | 22,849 | 9,732 | 58,534 |

Source: Raaphorst and Benninga (2019), adapted by Wageningen Economic Research.

[1] See Table 5.2.

Table 5.4 shows that when all imports of fresh tomatoes, peppers and cucumbers into the USA would be substituted by domestic greenhouse production a total labour need is required of 56.5-58.5m hours. The vast majority is required for cultivation labour (more than 90%). The remaining labour need is required for management activities of the entrepreneur.

# 6 Discussion and conclusions

## 6.1 Discussion

The future-proofing of new vegetable companies with greenhouses depends primarily on the ability to conclude supply contracts with retailers. The ability of companies to distinguish themselves in any way from other companies is decisive for this. Important are a constant supply of good product quality, a distinctive range and reliable year-round delivery. In addition, companies distinguish themselves, if they are able to supply a wide range vegetable types. It is possible to achieve this by growing more products or by cooperating and making agreements with fellow companies that grow other vegetables.

The price at which vegetables can be sold to wholesalers and/or retailers depends on the cost price, the competition on the market and to some extent the quality of the products. The costs of vegetables grown under glass in the US are apparently somewhat higher than that of vegetables imported from Mexico (including transportation costs), otherwise imports would hardly be attractive. On the other hand costs compared to vegetables grown under glass in Canada will probably be lower due to lower energy costs, based on the climate in Canada.

Greenhouse horticulture establishments also provides possibilities for employment. The estimation has been done on the information of the Dutch greenhouse vegetable sector. It is commonly known that the Dutch labour needs for cultivation activities is rather low, because of the high labour intensity. From that perspective a careful estimation has been conducted. The translation of labour needs into the number of full-fledged workers has been omitted because of the unknown number of regular working hours on an annual basis in the USA.

Growing in greenhouses provides a protected environment for the plants and their products. However, there are special circumstances where even greenhouses can no longer provide protection. These so-called calamities in the American situation include tornadoes, excessive snowfall and the chance of earthquakes. It requires a risk analysis whether greenhouse development in such a region will probably be attractive or not.

The investment opportunities for Dutch suppliers of greenhouse materials, seeds, fertilisers and plant protection products are clearly present, but are subject to various factors. It is the combination of competitive prices and services whether the Dutch greenhouse industry can benefit from the demand for greenhouse horticulture in the USA. In some cases Dutch greenhouses constructors operate as supervisor for the designing, building and maintenance process, including local or regional construction companies.

## 6.2 Conclusions

There is potential for newly established high-tech greenhouse for vegetable production in the USA, provided that market requirements can be met. Most important is that growers or producers realise contracts with retailers, whereby deliveries are made at a fixed price with a defined product quality criterion. Producers are in fact price takers and have limited influence on the price settings.

The advantages of protected cultivation compared to outdoor production of vegetables are the higher input efficiencies of water, nutrients and crop protection agents (physical consumption related to level of yield). Moreover, protected cultivation is less dependent on the climate factor.

The estimated potential greenhouse area to substitute imports of fresh vegetables into the USA is calculated at 7,000-8,000 ha. The highest number is based on an lower estimated yield per ha, the lowest area on an average estimated yield per ha. Artificial lighting is not yet considered, because the high radiation sum in the selected states of the USA does not make artificial lighting immediately necessary. In principle artificial lighting is most promising in vegetable production for the high-end market with higher prices for premium products, like cocktail and cherry tomatoes.

The estimated potential greenhouse area for fresh vegetable production in the USA corresponds with a total investment sum of USD 9,575-10,915m.

This estimated investment sum is about 200 times higher than the export of Dutch greenhouses materials to the USA in 2018. A rough estimation is that Dutch greenhouse constructors could reach a share of 5-10% (10-20 times more in value than now). Following the greenhouse builders, suppliers of fertilisers and pesticides can also benefit from this to the same extent with a share of 5-10%).

The estimated area of greenhouse horticulture establishments will provide employment of 56.5-58.5m hours, of which more than 90% for cultivation labour. Within the scope of this study no answers could be given whether this labour need can be met with local (skilled) people or whether migrant labourers should meet this need.

From the above-mentioned points no firm conclusions can be drawn, because the study is an exploration of the potential and opportunities of high-tech greenhouse production in the USA. Many (biophysical and social) factors determine whether the opportunities can be capitalized.

# 7 Recommendations

The opportunities for establishing high-tech greenhouses in the Midwest, East Coast region and the state California, is related to local and regional biophysical conditions such as climate, infrastructure (roads and resources) and distance to the markets. This might be worked out in more detail in a follow-up of this study. In this study also other links of the supply chain, such as suppliers of fertilisers, plant protection products and even planting material should be taken into account.

Since greenhouse horticulture establishments provide opportunities for employment (both cultivation as well as management labour) a more thoroughly study would be required to make precise estimations. Moreover it should be taken into account whether sufficient qualified labour is available regionally, because this is a prerequisite for starting a greenhouse operation. In that case, agricultural education and training should be considered to what extent the need for employment with local people can be met.

Artificial lighting in greenhouses seems not be immediate necessary regarding the high radiation sums in the selected regions and states of the USA. Nevertheless it is recommended to look into that more specifically, depending on the product type and the targeted market segments (e.g. high-end market). Artificial lighting is not always for every crop the ultimate and only solution. Other alternatives vegetables to produce in greenhouses are leafy vegetables, herbs, ornamentals or crops with high nutritional contents.

High-tech greenhouses require high investments. These investments exceed some of the current growers, because the investments can be higher than growers are able or willing to take on. Additional research may be conducted to look for special funds or other forms of stimulation.

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# Appendix 1 Investments and investments costs of greenhouses

*Investments and investments costs of greenhouses (1,000 euros) for a greenhouse of 2 ha*

| Equipment | Investment | Depreciation | Maintenance costs |
|---|---|---|---|
| Standard Venlo greenhouse | 1,094 | 75 | 5 |
| Earthwork | 54 | | |
| Floors, pavement | 810 | 57 | 8 |
| Drainage | 54 | 4 | 1 |
| Nursery building | 203 | 14 | 1 |
| Cold rooms 300 $m^3$ | 54 | 4 | |
| Boiler house | 58 | 4 | |
| Energy utilities | 30 | 2 | |
| Electricity pipes | 304 | 2 | |
| Boiler | 174 | 12 | 2 |
| Condenser | 32 | 4 | |
| Heat storage | 338 | 24 | 7 |
| Heating system | 181 | 13 | 1 |
| Main pipe heating | 157 | 11 | 1 |
| $CO_2$ installation via boiler | 18 | 2 | 1 |
| Climate computer | 41 | 6 | 3 |
| Energy screen | 392 | 55 | 20 |
| Substrate system | 24 | 2 | |
| Rock wool | 297 | 25 | |
| Substrate poured | 204 | 25 | 2 |
| Drainage system | 124 | 10 | |
| Fertilisation | | | |
| Dosing unit | 64 | 4 | 3 |
| A and B fry | 26 | | |
| Water unit | | | |
| Watering system | 35 | 5 | |
| Water storage | 61 | 6 | 3 |
| Disinfection | 63 | 6 | 3 |
| Reverse osmosis | 96 | 6 | 2 |
| Crop protection | | | |
| crop protection robot | 32 | 3 | 2 |
| Sorting | | | |
| Sorting unit | 230 | 23 | 11 |
| Transport | | | |
| Internal transport | 54 | 5 | 3 |
| Total | 5,032 | 416 | 84 |
| Artificial lighting | | | |
| Heat power installation | 446 | 44 | 2 |
| Lamp fixtures | 567 | 85 | 1 |
| Lamps (600 W 0,16 per $m^2$) | 73 | 24 | |
| Cable | 62 | 9 | |
| Sub Total | 1148 | 163 | 3 |
| Total | 6,180 | 579 | 87 |

*Investments and investments costs of greenhouses (1,000 euros) for a greenhouse of 4 ha*

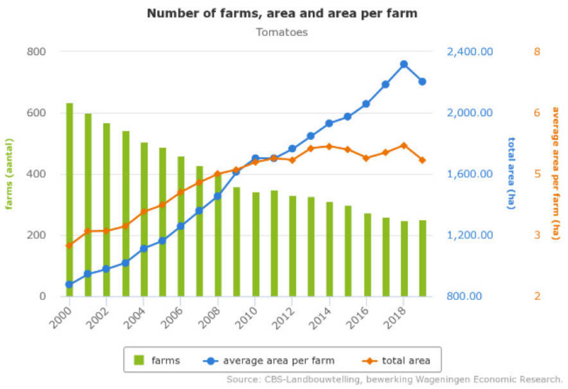
| Equipment | Investment | Depreciation | Maintenance costs |
|---|---|---|---|
| Standard Venlo greenhouse | 2,133 | 149 | 11 |
| Earthwork | 108 | | |
| Floors, pavement | 1,620 | 113 | 16 |
| Drainage | 108 | 8 | 1 |
| Nursery building | 203 | 14 | 1 |
| Cold rooms 300$m^3$ | 61 | 5 | |
| Boiler house | 58 | 4 | |
| Energy utilities | 30 | 2 | |
| Electricity pipes | 30 | 2 | |
| Boiler | 182 | 13 | 2 |
| Condenser | 34 | 5 | |
| Heat storage | 473 | 33 | 9 |
| Heating system | 362 | 25 | 1 |
| Main pipe heating | 162 | 11 | 2 |
| CO2 installation via boiler | 20 | 2 | 1 |
| Climate computer | 44 | 7 | 1 |
| Energy screen | 83 | 110 | 39 |
| Substrate system | 49 | 5 | 1 |
| Rock wool | 594 | 49 | |
| Substrate poured | 408 | 50 | 4 |
| Drainage system | 248 | 10 | |
| Fertilisation | | | |
| Dosing unit | 68 | 4 | 3 |
| A and B fry | 28 | | 1 |
| Water unit | | | |
| Watering system | 70 | 10 | 3 |
| Water storage | 68 | 7 | 2 |
| Disinfection | 68 | | |
| Reverse osmosis | 96 | 10 | 3 |
| Crop protection | | | |
| crop protection robot | 54 | 5 | 3 |
| Sorting | | | |
| Sorting unit | 338 | 34 | 17 |
| Transport | | | |
| Internal transport | 61 | 6 | 3 |
| Total | 8,559 | 704 | 133 |
| Artificial lighting | | | |
| Heat power installation | 915 | 91 | 5 |
| Lamp fixtures | 1,162 | 174 | 2 |
| Lamps (600 W 0,16 per $m^2$) | 149 | 49 | |
| Cable | 128 | 19 | |
| Sub total | 2,354 | 324 | 7 |
| Total | 10,913 | 1,028 | 140 |

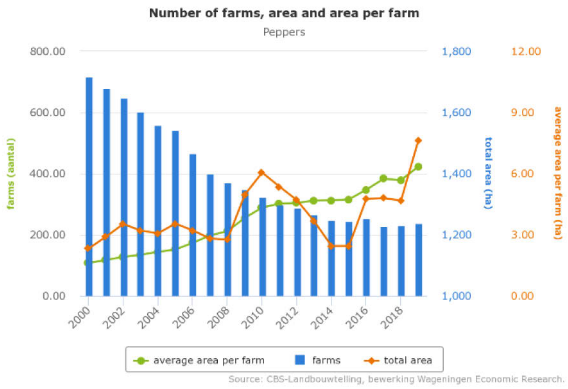
*Investments and investments costs of greenhouses (1,000 euros) for a greenhouse of 10 ha*

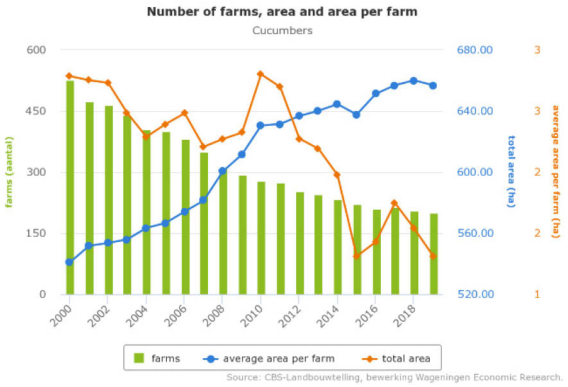
| Equipment | Investment | Depreciation | Maintenance costs |
|---|---|---|---|
| Standard Venlo greenhouse | 5,333 | 373 | 267 |
| Earthwork | 236 | | |
| Floors, pavement | 371 | 26 | 4 |
| Drainage | 236 | 17 | 2 |
| Nursery building | 304 | 21 | 2 |
| Cold rooms 300m$^3$ | 74 | 6 | 2 |
| Boiler house | 61 | 4 | |
| Energy utilities | 34 | 2 | 1 |
| Electricity pipes | 48 | 3 | 1 |
| Boiler | 191 | 13 | 2 |
| Condenser | 34 | 5 | |
| Heat storage | 506 | 35 | 10 |
| Heating system | 830 | 58 | 4 |
| Main pipe heating | 167 | 12 | 1 |
| CO2 installation via boiler | 23 | 2 | 1 |
| Climate computer | 47 | 7 | 4 |
| Energy screen | 1,600 | 224 | 80 |
| Substrate system | 108 | 11 | 1 |
| Rock wool | 1,316 | | |
| Substrate poured | 817 | 98 | 8 |
| Drainage system | 557 | 111 | |
| Fertilisation | | | |
| Dosing unit | 72 | 11 | 4 |
| A and B fry | 34 | 4 | 1 |
| Water unit | | | |
| Watering system | 169 | 25 | 8 |
| Water storage | 68 | 7 | 3 |
| Disinfection | 71 | 11 | 4 |
| Reverse osmosis | 97 | 10 | 2 |
| Crop protection | | | |
| crop protection robot | 58 | 6 | 3 |
| Sorting | | | |
| Sorting unit | 810 | 45 | 23 |
| Transport | | | |
| Internal transport | 78 | 8 | 4 |
| Total | 14,350 | 1157 | 200 |
| | | | |
| Artificial lighting | | | |
| Heat power installation | 2,125 | 212 | 11 |
| Lamp fixtures | 2,700 | 405 | 4 |
| Lamps (600 W 0,16 per m$^2$) | 346 | 114 | 1 |
| Cable | 297 | 44 | 1 |
| Sub total | 5,068 | 775 | 17 |
| Total | 19,418 | 1932 | 217 |

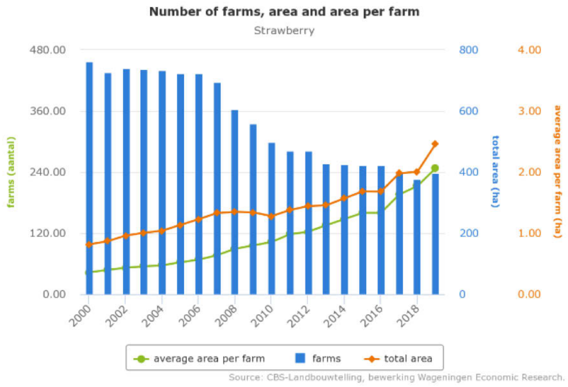
Source 1a, 1b, 1c: Kwantitatieve Informatie 2019 (Raaphorst and Benninga, 2019), adapted for the American situation by Wageningen Economic Research

# Appendix 2 Number of farms, area and area per farm of greenhouses tomatoes, pepper, cucumber and strawberry in the Netherlands

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Wageningen Economic Research
REPORT
2020-054

The mission of Wageningen University & Research is "To explore the potential of nature to improve the quality of life". Under the banner Wageningen University & Research, Wageningen University and the specialised research institutes of the Wageningen Research Foundation have joined forces in contributing to finding solutions to important questions in the domain of healthy food and living environment. With its roughly 30 branches, 5,000 employees and 12,000 students, Wageningen University & Research is one of the leading organisations in its domain. The unique Wageningen approach lies in its integrated approach to issues and the collaboration between different disciplines.

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