



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

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

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

Wageningen Economic Research
Wageningen, July 2020

In this version, published on 6 August 2020, some minor edits have been carried through. The edits mainly concern grammar and phrasing and do not affect the contents.

REPORT
2020-054
ISBN 978-94-6395-464-8

Marc Ruijs, Jan Benninga, 2020. *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*. Wageningen, Wageningen Economic Research, Report 2020-054. 46 pp.; 12 fig.; 15 tab.; 28 ref.

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

This report can be downloaded for free at <https://doi.org/10.18174/526843> or at www.wur.eu/economic-research (under Wageningen Economic Research publications).

© 2020 Wageningen Economic Research
P.O. Box 29703, 2502 LS The Hague, The Netherlands, T +31 (0)70 335 83 30,
E communications.ssg@wur.nl, <http://www.wur.eu/economic-research>. Wageningen Economic Research is part of Wageningen University & Research.



This work is licensed under a Creative Commons Attribution-Non Commercial 4.0 International License.

© Wageningen Economic Research, part of Stichting Wageningen Research, 2020
The user may reproduce, distribute and share this work and make derivative works from it. Material by third parties which is used in the work and which are subject to intellectual property rights may not be used without prior permission from the relevant third party. The user must attribute the work by stating the name indicated by the author or licensor but may not do this in such a way as to create the impression that the author/licensor endorses the use of the work or the work of the user. The user may not use the work for commercial purposes.

Wageningen Economic Research accepts no liability for any damage resulting from the use of the results of this study or the application of the advice contained in it.

Wageningen Economic Research is ISO 9001:2015 certified.

Wageningen Economic Research Report 2020-054 | Project code 2282200573

Cover photo: Shutterstock

Contents

	Preface	5
	Summary	5
	S.1 Primary outcomes	6
	S.2 Other outcomes	6
	S.3 Method	6
1	Introduction	7
	1.1 Background	7
	1.2 Objectives	7
	1.3 Reading guide	8
2	Methods	9
3	High-tech greenhouse vegetable production in the Netherlands	10
	3.1 Structure	10
	3.2 Economic performance	13
	3.3 Trade	17
	3.4 Sustainability performance	19
4	Vegetable production in the USA	22
	4.1 Domestic production	22
	4.1.1 Acreage	22
	4.1.2 Growing conditions	22
	4.1.3 Availability of energy and CO ₂	24
	4.1.4 Growing media	24
	4.1.5 Fertilisers	24
	4.1.6 Availability of water and water quality	24
	4.1.7 Planting material	25
	4.1.8 Production and cultivation system	25
	4.1.9 Climate change	26
	4.2 Domestic consumption, production and imports of fresh vegetables	26
	4.3 Supply of vegetables	26
	4.4 USA domestic market competition	27
	4.5 Cost price components	27
	4.6 Availability of labour	28
5	Opportunities of high-tech greenhouses for the vegetable supply chain in the USA	31
	5.1 Market	31
	5.2 Available suitable areas	31
	5.3 Sustainability requirements	31
	5.4 Investments in high-tech greenhouses	32
	5.5 Estimation of production potential and investments opportunities	32
	5.6 Estimation of labour need	34
6	Discussion and conclusions	36
	6.1 Discussion	36
	6.2 Conclusions	36

7	Recommendations	38
	References and websites	39
	Consulted persons	41
	Appendix 1 Investments and investments costs of greenhouses	42
	Appendix 2 Number of farms, area and area per farm of greenhouses tomatoes, pepper, cucumber and strawberry in the Netherlands	45

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.



Ir. O. (Olaf) Hietbrink
Business Unit Manager Wageningen Economic Research
Wageningen University & Research

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 CO₂. 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 benefits 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 depend on 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

This study is commissioned and financed by the Netherlands embassy in Washington, D.C. and the Netherlands Consulate in Chicago, the Netherlands Enterprise Agency and NL Works. An exploratory study has been conducted by Wageningen Economic Research on 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 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 of 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 US Secretary of Agriculture, Sonny Purdue, also expressed an interest in Dutch greenhouse horticulture. 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 the interest in Dutch greenhouse horticulture 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. These areas are of special interest to the Netherlands 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, which will be used to identify 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. First the market potentials of protected cultivation and opportunities for the Dutch supplying industry was looked at, followed by the environmental aspects.

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 Netherlands 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 Agricultural Counselor 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 the publication 'Kwantitatieve Informatie voor de Glastuinbouw' (Raaphorst and Benninga, 2019), additional information from Dutch greenhouse builders 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.

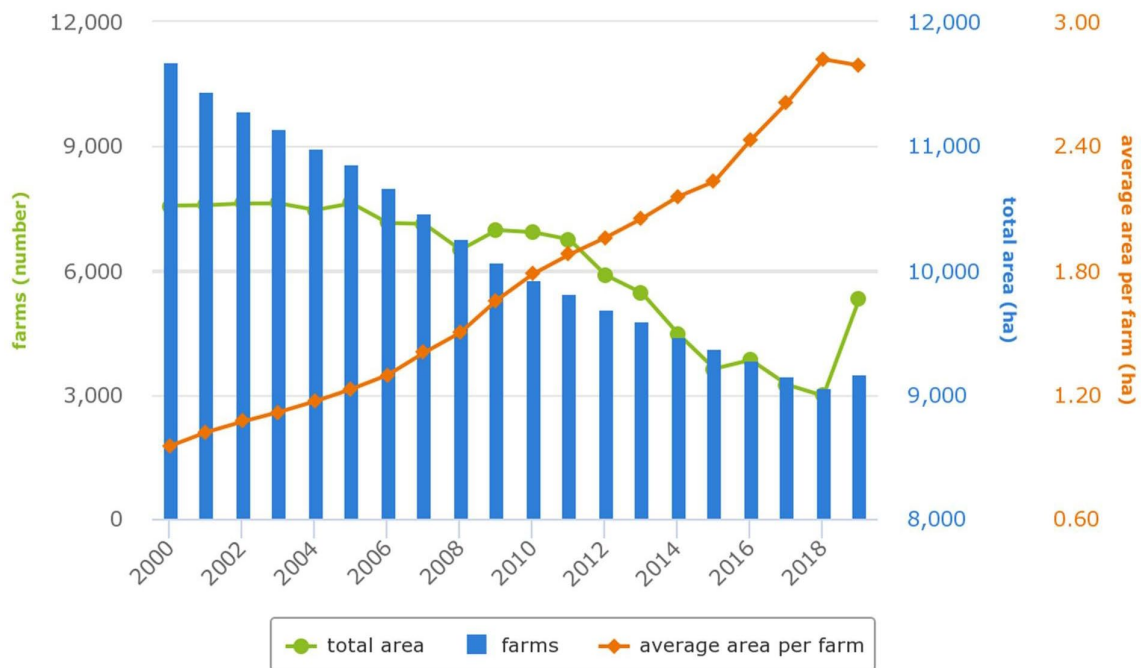
In this exploratory study figures are used and estimates are made for an average or general situation. No considerations are taken into account for differences in climate and other bio-physical conditions between the different regions and states, because this requires more in-depth research and more 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.



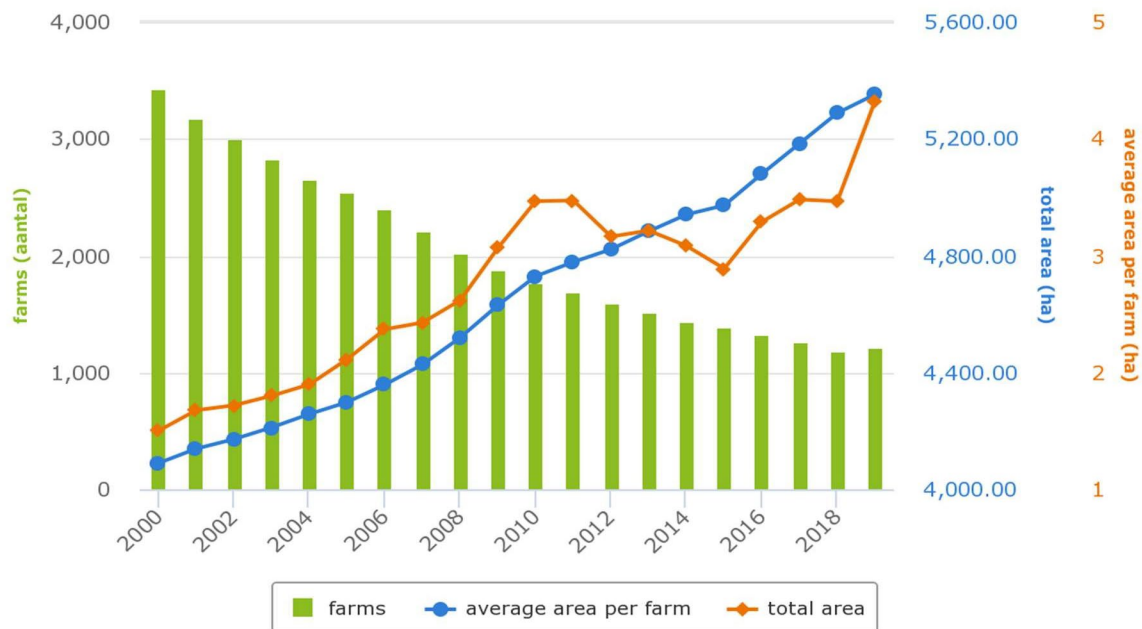
Source: CBS-Landbouwtelling, bewerking Wageningen Economic Research.

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.



Source: CBS-Landbouwtelling, bewerking Wageningen Economic Research.

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 8°C, 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 (m ² greenhouse area)	10,000	15,000	20,000	40,000	100,000
Business type					
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 m ²	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 m ²	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 m ²	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.

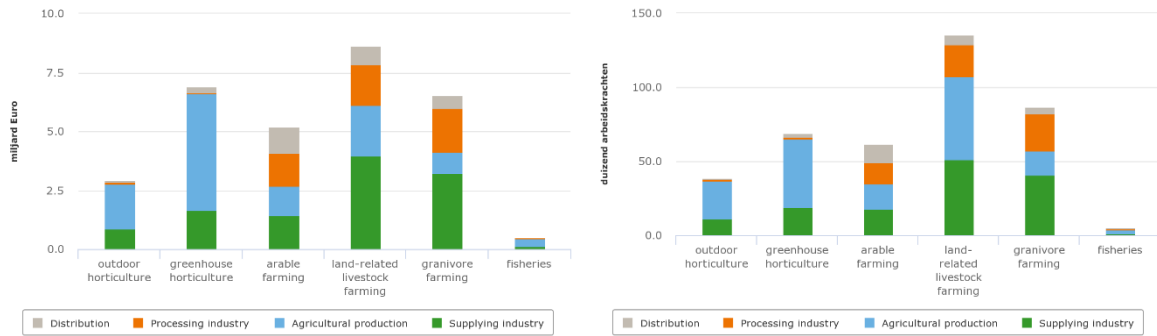


Figure 3.4 Economic importance of different agricultural sectors and the distribution within the chain in the Netherlands in 2017 (agrimatie.nl)

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.

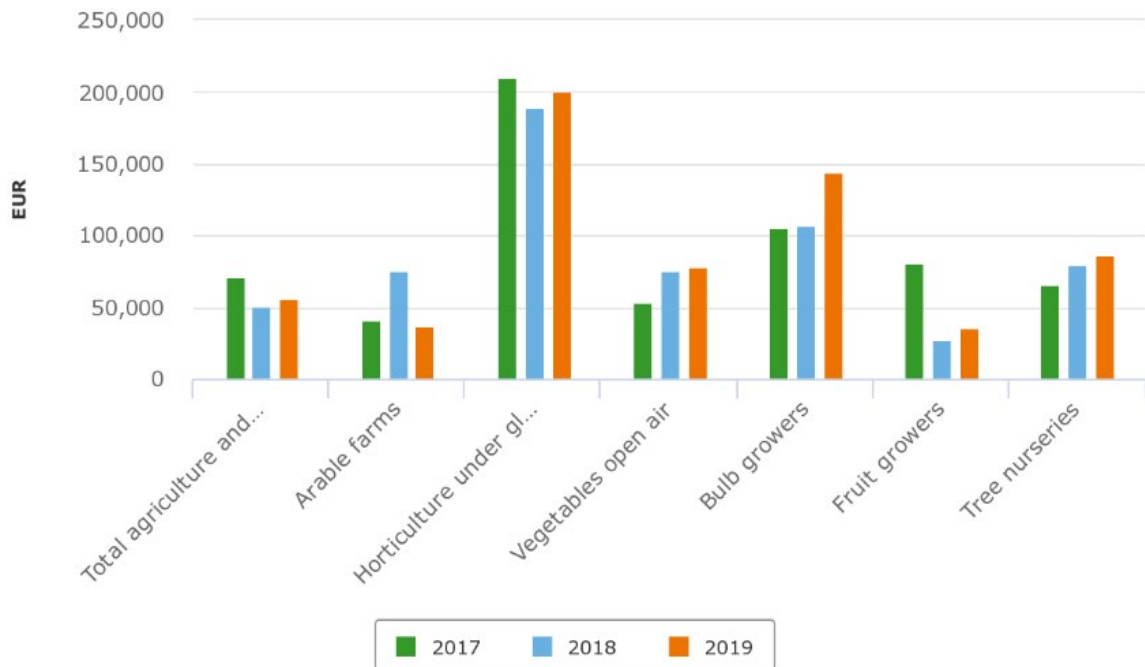


Figure 3.5 Family income per unpaid labour working unit (euro) (agrimatie.nl)

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.

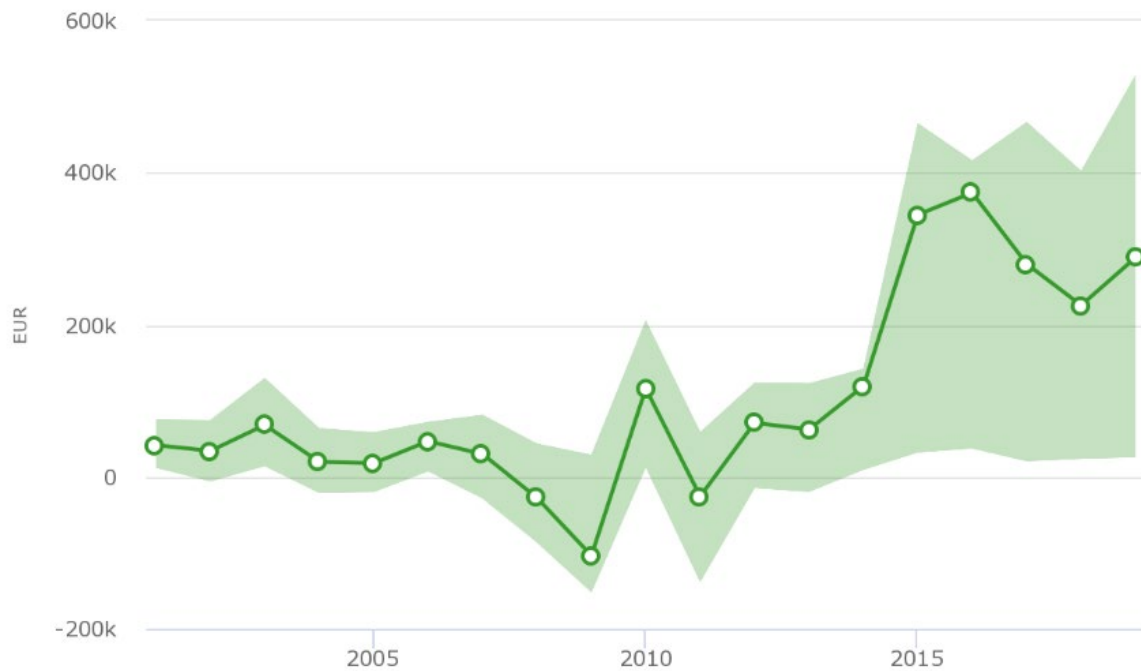


Figure 3.6 Family income per unpaid labour working unit and the lower (20% level) and upper level (80% level) (euro) (agrimatie.nl)

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.

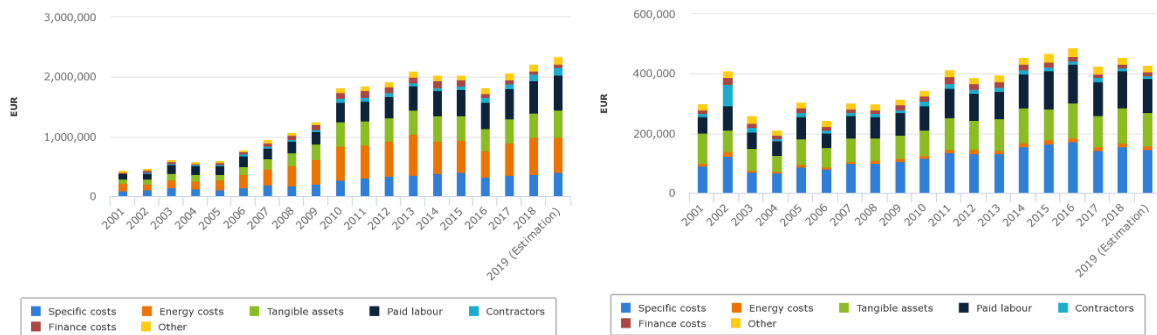


Figure 3.8 Average costs component of greenhouse vegetable farms and outdoor vegetables farms (euros) (agrimatie.nl)

As can be expected the total costs of greenhouse vegetable farms are to a substantial part determined by the energy costs compared to 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 3.2. 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 3.2. offers insight into the separate costs of production.

Table 3.2 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	432,000
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 the size and dimension of the Dutch trade and supply chain for fruits and vegetables. The economic importance of the horticultural sector does not only depend on their domestic production, but even more on their trading activities (see import figures).

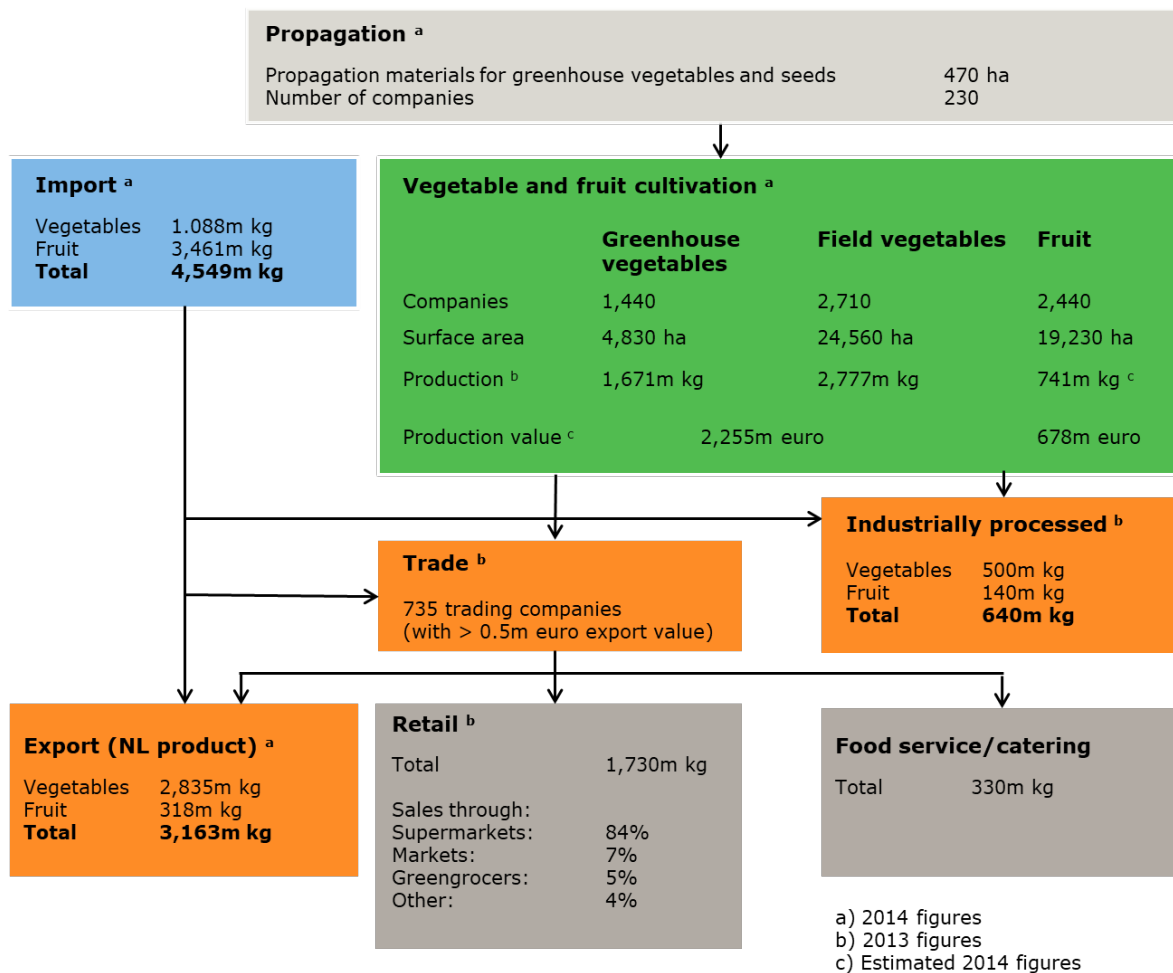


Figure 3.9 Schematic overview of the Dutch vegetable and fruit supply chain, 2014

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 for 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 3.3 *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
<i>By product group (2-digit GN code)</i>		<i>% By product group</i>			
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 Wageningen Economic Research.

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 been severely impacted, 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 CO₂ application. In Figure 3.10 the energy consumption of greenhouse vegetable farms and outdoor vegetable farms is shown.

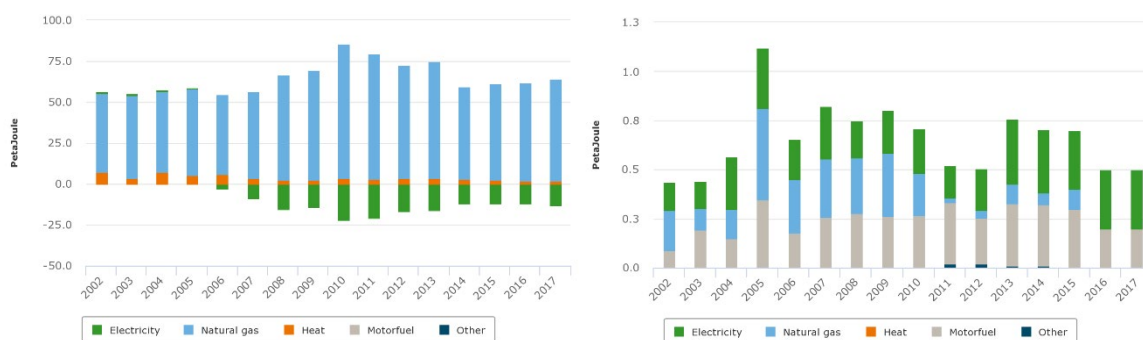


Figure 3.10 Average energy use on greenhouse vegetable and outdoor vegetable farms (agrimatie.nl)

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 CO₂ 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 CO₂. 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 met 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).

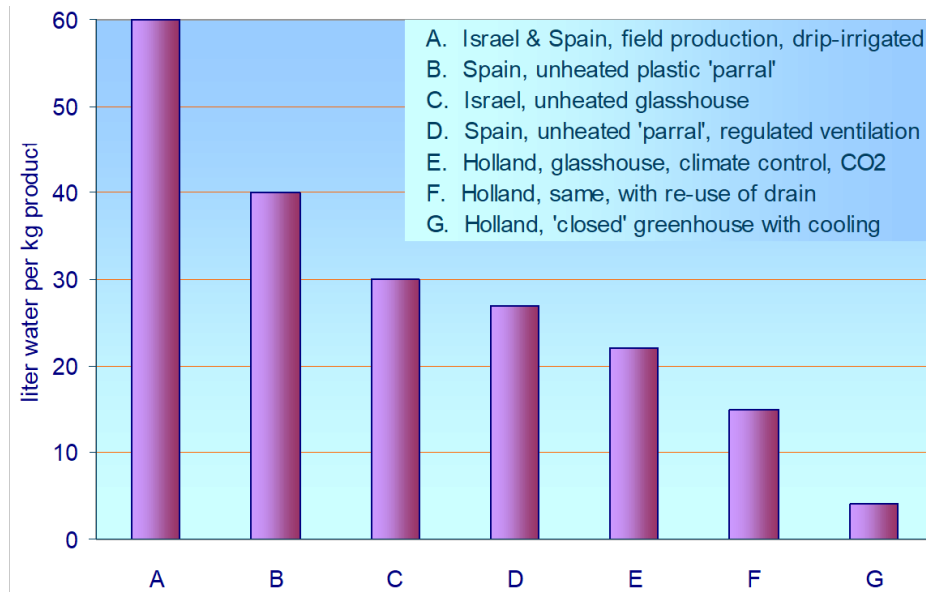


Figure 3.11 Water use (litres per kg tomato) of tomato production in various growing systems in different countries. The technology content increases rightwards

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 3.2). 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 3.2, 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 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 CO₂, substrate, the fertiliser supply, and the availability and quality of water.

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

Table 4.2 Average radiation sum (kWh/m²) per month for the different states in the USA and for comparison, the Netherlands

	Month												Total
	1	2	3	4	5	6	7	8	9	10	11	12	
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/m² 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 May 1st. This is above 4.6 kWh/m² 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 for Kentucky and New

Hampshire which do not have this disadvantage due to more moderate temperatures. The chance of days with a temperature above 30°C 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 CO₂

In some periods of the year, especially during the 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, biomass, natural gas or propene, which are indispensable for greenhouse production, are also available under extreme circumstances.

One of the building elements of growth is CO₂ and this can be the growth limiting factor under high radiation conditions. CO₂ can be applied during cultivation in greenhouses, either in the form of flue gases (from the boiler) or in the form of pure CO₂ that is purchased. It can be assumed that the CO₂ 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 are available, such as rockwool, cocopeat, volcanic 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 is the best option, due to its high quality for vegetable growing, regardless of whether it is for 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 have 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 focused 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 better controlled - are more suitable for achieving higher product quality and 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

Within fifty years, climate change will 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 km². Due to 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

Data about 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 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 quantity 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.

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

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

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 m³ 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.

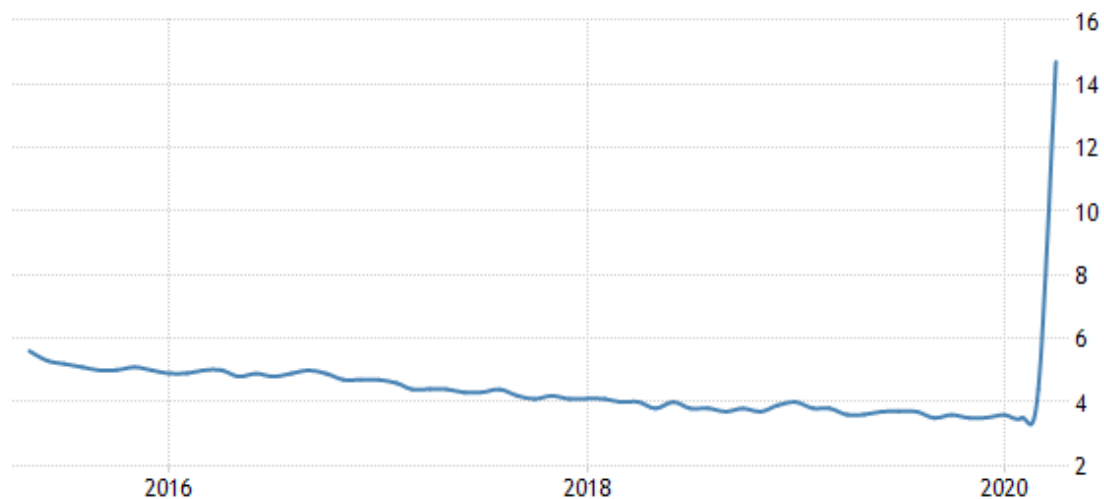
The price of natural gas differs per state. The energy costs will be the lowest when the energy price in combination with temperatures are the most favourable.

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).



SOURCE: TRADINGECONOMICS.COM | U.S. BUREAU OF LABOR STATISTICS

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 the 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 for 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 flat. 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 a 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/m². In mid-tech, plastic, greenhouses the yield can increase to about 20-30 kg/m², while in high-tech, plastic or glass, greenhouses the yield can go up to 40-70 kg/m², 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/m² (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/m² (range 50-60 kg/m²) 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/m² (range 60-70 kg/m²). 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 CO₂ 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/m² (range 32-38 kg/m²).

For cucumber (three cropping system) the yield in these USA states is estimated at 240 pieces/m² or 103 kg/m² (range 230-250 pieces/m² or 98.7-107.3 kg/m²) (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	kg/m ²				
Standard level		65	35	103	
Lower level	kg/m ²	58	30	93	
Acreage at	ha				
Standard level		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	
					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 builders from the USA and from other countries such as 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 found 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 estimate 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 quality products, a distinctive range and reliable year-round delivery. In addition, companies can 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 in 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 provide possibilities for employment. The estimate has been done based on the information of the Dutch greenhouse vegetable sector. It is commonly known that the Dutch labour needs for cultivation activities are rather low, because of the high labour productivity. 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 defined product quality criteria. 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 greenhouse materials to the USA in 2018. A rough estimate is that Dutch greenhouse constructors could reach a share of 5-10% (10-20 times more in value than now). In addition to greenhouse builders, suppliers of greenhouse products, such as fertilisers, pesticides, seeds, etc., 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, depend on 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 thorough study would be required to make precise estimates. 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 due to 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 alternative vegetables to produce in greenhouses are leafy vegetables, herbs, ornamentals, or crops with high nutritional contents.

High-tech greenhouses require high investments. These investments can exceed the amount some of the current growers are willing to take on. Additional research may be conducted to look for special funds or other forms of financial opportunities.

References and websites

- Bame, M., S.G. Bullen (2007). A cost assessment of growing greenhouse tomatoes in North Carolina, PDF, NC State Extension.
- Benninga, J, W. Hennen, Y. Dijkxhoorn and M. van Galen (2017). Internationaal Productie Potentie Model: Model beschrijving sierteelt, Landbouw Economisch Instituut Nota 2017-023, Den Haag.
- Dutch Ministry of Agriculture, Nature & Food Quality (2020). Agroberichten buitenland 2020>Actueel>Nieuws>Nederlandse kassen belofte voor Amerikaanse Midwest.
- Garming, H. Tomatoes are the superlative vegetable; Global per capita consumption is 20 kg per year.
- Jukema, G.D., P. Ramaekers and P. Berkhout (eds.) (2020). De Nederlandse agrarische sector in internationaal verband. Wageningen/Heerlen/Den Haag, Wageningen Economic Research en Centraal Bureau voor de Statistiek, Rapport 2020-001. 172 blz.
- Kaiser, C. and M. Ernst (2018). Field-town Tomatoes, Center for crop diversification, Kentucky.
- Karnin, A. (2019). Trump say U.S. will hit Mexico with 5% tariffs on all goods, The New York Times, 30 May 2019.
- KPMG (2020). Trade and customs – KPMG global – KPMG Intern, Trade agreement between Canada, Mexico, U.S. enters into force, July 1, 2020, 28 April 2020.
- Miller, C. (2019). Consumption is up; Production is down; Understand how fresh tomato trends affect you, Growing Produce, April 2019.
- National Geographic.com (2017). This tiny country feeds the world.
- National Geographic (2020). Special edition. 50 Jaar Earth Day. Hoe we de grip verliezen; Een pessimistische visie op de aarde in 2070. Nr. 4-2020; 48-55.
- Persson, M. (2019). In het arme steenkoolzwarte Kentucky gloort gouden toekomst, de Volkskrant 7-10-2019.
- Raaphorst, M. and J. Benninga (2019). Kwantitatieve Informatie voor de Glastuinbouw (KWIN), Edition 26. Report GTB-5121, Bleiswijk.
- Ruijs, M. (2021). The global market size of greenhouse production, market trends and developments. Report 2018-113C (to be published in 2021). Wageningen, Wageningen Economic Research.
- Schneider, K. (2019a). AppHarvest's big idea: Bringing food production indoor at a mammoth Kentucky Greenhouse, <http://modeshift.org>.
- Schneider, K. (2019b). A Greenhouse large enough to feed the eastern seaboard, The New York Times, September 3.
- Selina, P. and M.E. Bledsoe (2002). U.S. Greenhouse/Hothouse Hydroponic Tomato Timeline.
- Stanghellini, C. (2014). Water use efficiency in tomato production. *Acta Horticulturae*, 1034: (25-32).
- Statistica (2020). The statistics portal for market data, market research and market studies.
- US Department of Agriculture, Tomato consumption in the United States and its relationship to US Department of Agriculture food pattern.
- UN Comtrade (2019).
- USDA (2019). Production statistics.
- USDA (2007). Consumer Brochure, National Organic Program.
- US Energy Information Administration (2019).
- Vanthoor, B.H.E., J.C. Gázquez, J.J. Magán, M.N.A Ruijs, E. Baeza, C. Stanghellini, E.J. van Henten and P.H.B Visser (2012). A Methodology For Model-Based Greenhouse Design: Part 4, Economic Evaluation Of Different Greenhouse Designs: A Spanish Case. *Biosystems Engineering* (online 2012), DOI: 10.1016/j.biosystemseng.2011.12.008, 14 pp.
- Velden, N. and P. Smit (2019). Energiemonitor van de Nederlandse glastuinbouw in Nederland 2018. Wageningen, Wageningen Economic Research, Rapport 2019-111, 62 blz.
- Wat eet Nederland (2020).
- Zakelijk banen.com (2020). Minimum loon Verenigde Staten. Source Energy

Websites

www.agrimatie.nl

www.nationalgeographic.com/magazine/2017/09/holland-agriculturesustainable-farming/

www.Stratista.com 2020

www.Wat eet nederland.nl 2020

www.Zakelijk banen.com 2020

Consulted persons

E. Breman	Dutch Embassy in Washington
J. Janse	Wageningen Plant Research /BU Greenhouse Horticulture
G. Jukema	Wageningen Economic Research
J. Webb	AppHarvest, Kentucky
D. Nichols	AppHarvest, Kentucky
J. Ball	SOAR, Kentucky

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

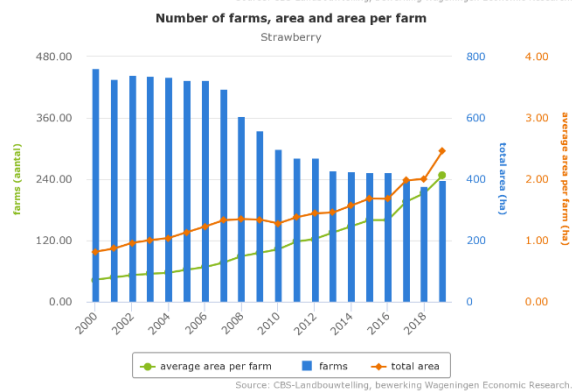
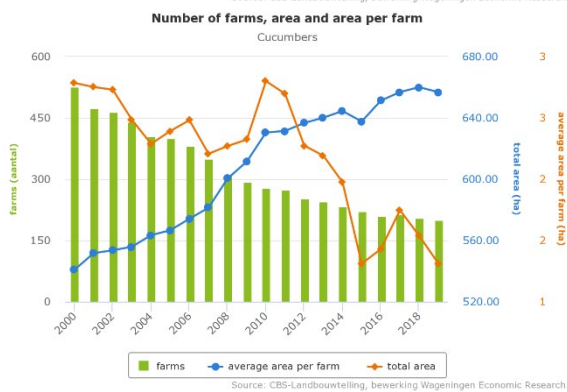
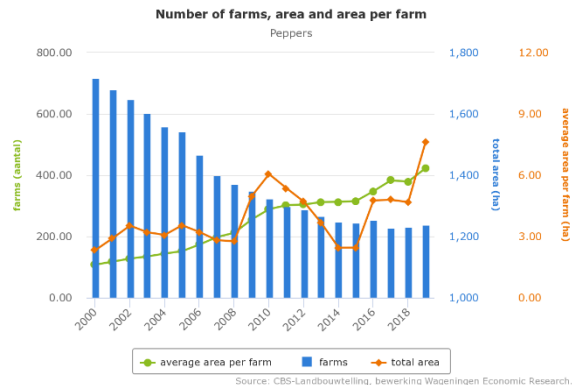
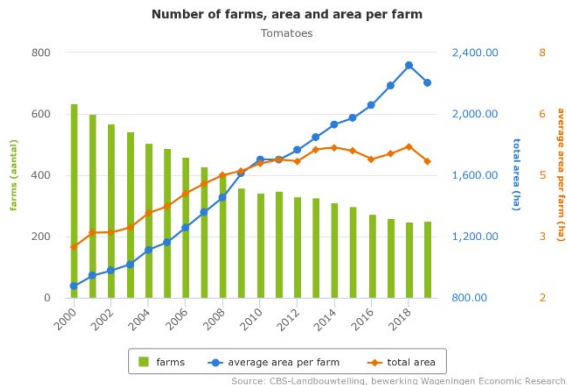
Equipment	Investment	Depreciation	Maintenance costs
Standard Venlo greenhouse	2,133	149	11
Earthwork	108		
Floors, pavement	1,620	113	16
Drainage	108	8	1
Nursery building	203	14	1
Cold rooms 300m ³	61	5	
Boiler house	58	4	
Energy utilities	30	2	
Electricity pipes	30	2	
Boiler	182	13	2
Condenser	34	5	
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



www.agrimatie.nl

Wageningen Economic Research
P.O. Box 29703
2502 LS The Hague
The Netherlands
T +31 (0)70 335 83 30
E communications.ssg@wur.nl
www.wur.eu/economic-research

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.



To explore
the potential
of nature to
improve the
quality of life



Wageningen Economic Research
P.O. Box 29703
2502 LS Den Haag
The Netherlands
T +31 (0)70 335 83 30
E communications.ssg@wur.nl
www.wur.eu/economic-research

Report 2020-054
ISBN 978-94-6395-464-8

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.

