Business case for large scale crop production in greenhouse facilities in Iceland for the global market

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Report WPR-1049

WAGENINGEN
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Referaat
IJsland heeft unieke omstandigheden en natuurlijke hulpbronnen die een duurzame productie van voedsel voor de export mogelijk zouden kunnen maken. Het onderzoek in dit rapport heeft geanalyseerd welke gewassen hiervoor geschikt zijn, wat de hiervoor benodigde technologie zou zijn, welke kosten en opbrengsten mogen worden verwacht en welke markten potentieel van deze export zouden kunnen profiteren. Resultaten geven aan dat er een haalbare businesscase voor diverse groenten en hoogwaardige gewassen mogen worden verwacht indien de luchtvrachtkosten kunnen worden verlaagd. Voor meer calorieën-rijke gewassen, zoals tarwe of rijst, is kasproductie geen optie en is er geen positieve businesscase mogelijk. IJsland is nog niet zelfvoorzienend voor verse groenten, hier is ruimte voor meer productie in eigen land. Deze studie presenteert, aan het voorbeeld van IJsland, een methodologie om de juiste gewaskeuze te maken, geschikte technologieën te selecteren en het marktpotentieel te beoordelen om een business case voor glastuinbouwproductie in een bepaald land te bepalen. Deze methodologie kan ook worden toegepast in elke andere regio's in de wereld.

Abstract
Iceland has unique conditions and natural resources that potentially allow a very sustainable production of food for export to the world. The present work has analyzed the technology required, the costs and the potential markets that could benefit from this export. Results indicate possible feasible business cases for vegetables and high value crops if air transport costs can be decreased. For more calory rich crops, such as wheat or rice, protected is not suitable to allow a positive business case. Iceland is still not self sustained for fresh vegetables, so there is room for increased production. This study shows a methodology to analyse crop choice, technology selection and market assessment for proteced cultivation at the example of Iceland. The methodology can be applied at any other region in the world.

Keywords: giga factory, high tech greenhouse, indoor farm, nutrition, food security, market assessment

Reportinfo
Report WPR-1049
Projectnumber: 3742295600
DOI: https://doi.org/10.18174/548322
Theme: Energy and Climate

This study was carried out by the Wageningen Research Foundation (WR) business unit Greenhouse Horticulture and was commissioned and financed by Earth 2.0 EHF and David Wallerstein. WR is part of Wageningen University & Research, the collaboration of Wageningen University and Wageningen Research Foundation.

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Executive summary

Despite of its northern latitude, Iceland has some unique characteristics which make the island a good candidate for the establishment and operation of protected vegetable production:
- It has abundant (almost) inhabited land.
- It has un unlimited supply of renewable energy (mostly geothermal and hydroelectric).
- Its climate is milder than that in other zones with similar latitude, thanks to the Gulf stream.

Therefore, the questions are:
- Can Iceland host giga scale factories for vegetable production and export to different world markets?
- Which crops could be produced competitively at a giga scale?
- How can productivity be improved by the technology of the growing system?
- How is resource use affected by climate?
- Which potential export markets to consider?

To answer these questions, a project has been carried by Wageningen University & Research Business Unit Greenhouse Horticulture (from now on WUR) in collaboration with Earth 2.0, which has been distributed with the following tasks:
1. Selection of 8 target crops which include a representation of healthy vegetables and highly nutritious fruits, tubers and cereals. This task has been accomplished by developing and applying a crop selection tool.
2. Different technical greenhouse and indoor factory designs and calculation of their resource use: For this, the adaptive greenhouse methodology developed by WUR has been applied. This methodology makes use of powerful simulation models to obtain accurate predictions of the greenhouse indoor microclimate, the required amount of some key resources (water, energy, CO_2, etc.) for production in both greenhouse and indoor factories as well as crop growth simulation models to predict potential crop yields. This has been done for 89 different scenarios.
3. Cost price calculations for produced food crops: data have been retrieved from different sources (Iceland, The Netherlands, etc.) to make the OPEX and CAPEX analysis and obtain the cost price for each studied scenario.
4. Market selection for food crops and data collection: a market selection tool has been developed and applied to select the most interesting 8 destination markets for export of the 8 selected products, making a total of 64 possible combinations. For each market data have been obtained on wholesale and transport price. The internal Icelandic market has also been considered.
5. Integration and presentation of the results: both the cost price analysis and the market information has been integrated in an Excel tool that can be used to visualize the main parameters of the economic balance (netto benefit, return of investment, etc.) for the 801 (89*9) scenario/market combinations.

Crop selection tool
The application of the crop selection tool has resulted in the following final crop list for this study, which includes a number of traditional greenhouse crops, for which there is a likely competitive advantage of growing under controlled conditions and a group of strategic/highly nutritious crops, which are normally grown in open field conditions (Table 1).

Table 1
List of selected crops.

Group	Crops
Vegetable group	Tomato, lettuce, sweet pepper, raspberry
Strategic/nutritious group	Potato, Rice, banana, avocado, rice

Different technical greenhouse and indoor factory designs and resource use calculation
A greenhouse design study was caaried out using the adaptive greenhouse design methodology of Vanthoor (2011) and the greenhouse climate and energy model described by de Zwart (1996) and the crop production model described by Marcelis *et al.* (2000).Two locations in Iceland, one in the South coast, represented by Keflavik, and one in the North coast, represented by Akureyri, were selected for this study and to carry out technical design simulations. Different yearly climate data sets were retrieved, analyzed and selected.
Two types of greenhouse crop production systems were studied: high tech greenhouse structures and indoor factory (only one level, so no vertical type). The greenhouse or indoor factory was equipped with different climate control equipment: a hot water heating system, artificial CO_2 enrichment, an energy saving screen and artificial lighting in the greenhouse, and active cooling/dehumidification, heating, CO_2 enrichment and artificial lighting in the infoor farm. Two different artificial lighting systems were simulated: High Vapour Pressure Sodium lamps (HPS) and Light Emitting Diode lamps (LED). Different ranges of lighting intensities and in the case of lettuce, also different temperature regimes, were simulated, In total 89 final technical scenarios that were simulated.

Table 2
Combinations of growing system, lamp type and locations analyzed.

	Lamp type	Location
Glass greenhouse	HPS lamps	Keflavík
		Akureyri
	LEDs	Keflavík
		Akureyri
Indoor farm	LEDs	independent from location

The design for each of the different technical design scenarios was based on a climate data analysis performed for the two locations.
For each scenario, then simulations were performed with:
- Greenhouse climate/indoor farm model to calculate indoor microclimate and resource use requirement to maintain the desired crop growing conditions.
- Crop model [tomato/lettuce] to calculate potential crop yield.
- For the other crops yield is estimated from calculated dry matter based on estimated photosynthesis rate.

A summary of the estimated required main resources for two crops (tomato and lettuce) is presented as an example (Table 2 and Table 3). the results show little differences between the two locations in Iceland. Heating requirements in Akureyri are slightly higher due to higher snowfall, thus more energy is required to melt the snow in the roof. Requirements of electricity by the indoor farm are approximately double of those from the greenhouse and they are coming from the artificial light that needs to fully replace sunlight. LED's use less electricity since they have a higher efficiency, but slightly more heating is needed to maintain the greenhouse climate set points to compensate for the lower radiative heat relased in relation the HPS lamps.

Table 3
Summary of main resources estimated by the model for a number of simulated scenarios for tomato.

tomato		Keflavik		Akureyri		Indoor farm
		HPS	LED	HPS	LED	LED
Electricity	GWh/(ha·y)	6.2	3.8	6.2	3.8	12.7
Heating	GWh/(ha·y)	3.8	5.1	4.2	5.6	
Total energy	GWh/(ha·y)	9.9	8.9	10.4	9.4	12.7
CO_2	t/(ha·y)	346	322	302	285	219

Cost price analysis for produced food crops
Operational cost (OPEX) and capital costs (CAPEX) have been determined following the method of "Quantitative information for the glasshouse horticulture 2019 (KWIN)" (Raaphorst *et al.* 2019). Earth 2.0 provided the most relevant operational costs in Iceland (labour, energy, water, etc.) and the rest of operational costs and the capital costs were obtained from the mentioned KWIN. Figure 1 is an example of the cost distribution for greenhouse tomato production in Akureyri, with an HPS lighting system with a nominal PAR intensity of 250 micromol/m²/s. The amount of resources come from the model predictions. The needed greenhouse structure and equipment was determined by the simulations.

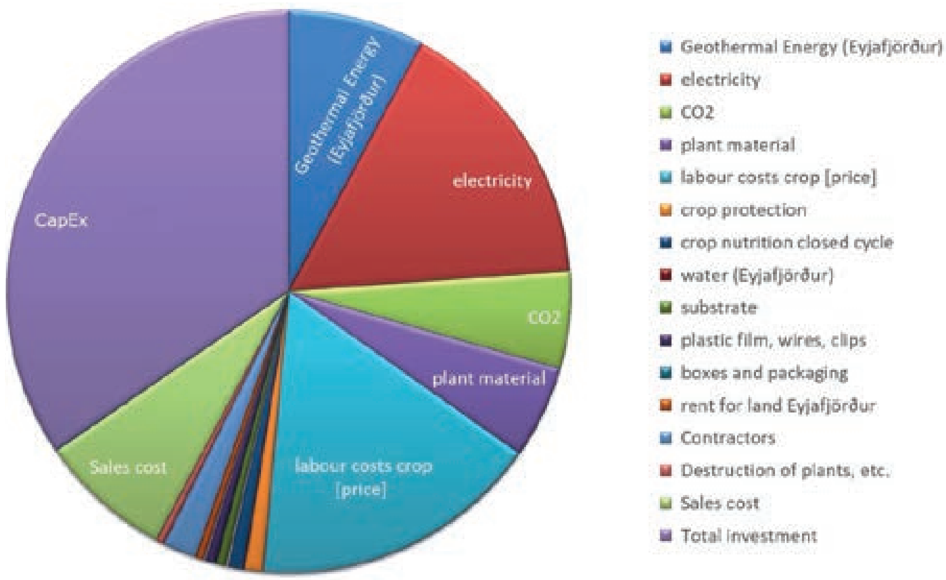

Figure 1 *Distribution of costs for a greenhouse tomato cultivated with HPS artificial light (250 micomol/m²/s) in Akureyri.*

We can clearly state that CapEx represents the largest share of the costs, followed by labour and electricity. This distribution is very similar for the 8 analyzed crops.

For every crop there is a potential yield estimation. Thus, the cost price each product has been established for all the analysed scenarios. For the Iceland market, the cost price excludes the transportation cost. In parallel, some recent information of retail prices the 8 products have been obtained by Earth 2.0, in the absence of an open observatory for wholesale prices. The wholesale price has been estimated for Iceland as 50% of the retail price (Figure 2).

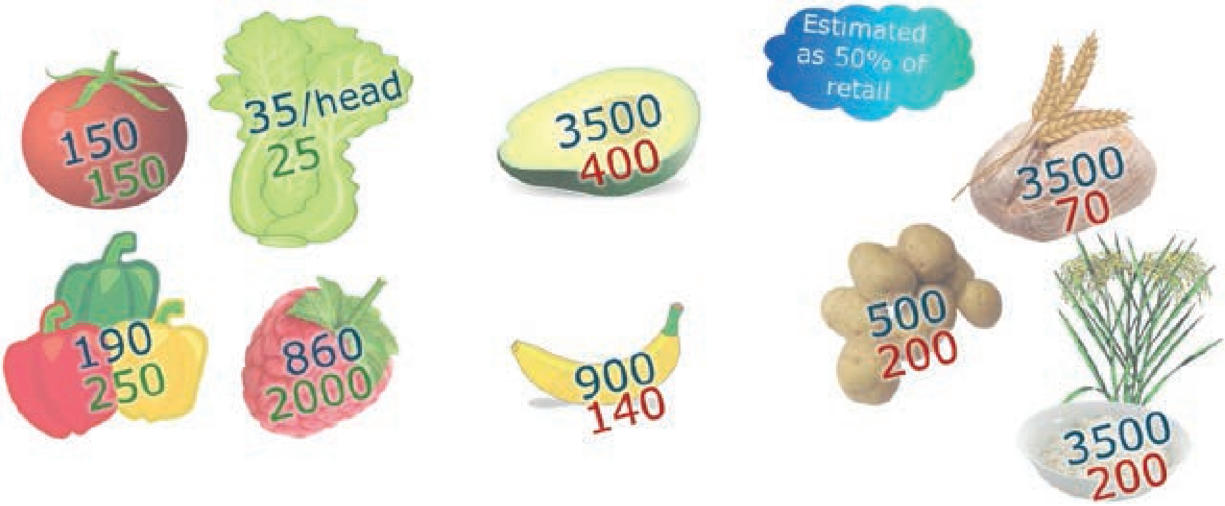

Figure 2 *Cost price (above, in blue) and wholesale price (below, in green when it is equal or higher than cost price in green, and in red when this is smaller).*

The main reason why the calorie and protein-rich crops have such high cost prices is that the harvestable fraction (harvest index) of these crops (grains, tubers and fruits) is rather low compared to that of vitamin and mineral-rich vegetable crops and in additions, they have a very high dry matter content (low water), which makes the productivity per unit area to be rather low, compared to the vegetables, which have a large water content. Therefore, calorie and protein-rich crops have a very low ratio between kg of dry matter produced and kg of yield (Table 5).

Table 4

Dry matter content, harvest index and ration between kg yield and kg of dry matter produced in a high tech greenhouse in Iceland for the 8 crops.

	dry matter (%)	harvest index (%)	kgyield kgdry
Lettuce	5	85	17
Tomato	5	65	13
Sweet pepper	8	60	7.5
Raspberry	15	40	2.7
Banana	20	40	2
Avocado	25	10	0.4
Potato	25	75	3
Rice	75	40	0.5
Wheat	75	40	0.5

Market selection for food crops

For the market selection, a similar methodology to the one used for the crop selection tool was applied. A total of 8 market indicators were selected, weighed and scored for a number of destination markets for each food crop (Table 5).

Table 5

Summary of main parameters used in the market selection tool.

Indicator	Weight	Definition	Source
Import price	Very high		UNComtrade
Import quantity	Very high	Average over last 3 years	UNComtrade
Availability per person	High	Calculated consumption per head population	FAOStat
GDP	High	Insight on hte ability to buy at high prices	World Bank
Import development	Fairly high	Yearly, based on 10 years	UNComtrade
Cost of cross border trade	Fairly high	Cost of trading across borders	World Bank
Apparemt availability	Low	Averege over last 3 years	FAOStat
Availability development	Low	Yearly, based on 10 years	FAOStat

Based on scores, 8 preferred markets were selected for each product, and information gathered on transport costs (both by sea and air freight, depending on the post-harvest life of each product) and wholesale prices.

Integration and presentation

The cost price analysis per produced food product for the different scenarios was integrated in an Excel tool together with the market information, allowing to get a picture of the potential combinations that could give a feasible business case. Below, we show the only two examples from all the studied combinations that provide positive combinations for export on giga scale at this moment: lettuce and raspberry. In both cases we have made calculations choosing the lowest cost prices scenario from those analyzed (Table 6 and Table 7).

Table 6

Summary of profit (ISK/head) achieved in different export markets for lettuce assuming the lowest cost price scenario analysed.

Best cost price 35/head	transport	total	local wholesale	profit
Slovenia	46.5	81.5	142.2	61
U.S.A.	108.4	143.4	352.1	209
Italy	46.5	81.5	199	117
Netherlands	46.5	81.5	142.2	61
Denmark	46.5	81.5	142.2	61
Germany	46.5	81.5	142.2	61
Hong Kong	108.4	143.4	56.8	-87
Sweden	46.5	81.5	142.2	61

Table 7
Summary of profit (ISK/kg) achieved in different markets for raspberry assuming the lowest cost price scenario analysed.

Best cost price 831.7 ISK/kg	transport	total	local wholesale	profit
U.S.A.	492.9	1324.5	2394	1069.4
Britain	211.2	1042.9	1391	348.4
Germany	211.2	1042.9	1267	224.5
Netherlands	211.2	1042.9	1267	224.5
Belgium	211.2	1042.9	1267	224.5
Switzerland	211.2	1042.9	1267	224.5
Spain	211.2	1042.9	985.7	-57.2
Portugal	211.2	1042.9	985.7	-57.2

For crops which are suited for sea freight, such as banana, the costs distribution indicates another large limiting factor in these crops if produced in greenhouses or indoor factories. A large proportion (ca. 75%) of CapEx OpEx costs (electricity, heat, CO_2) of these costs are not required for open field production, next to the productivity, making indoor farming non-competitive (Figure 3).

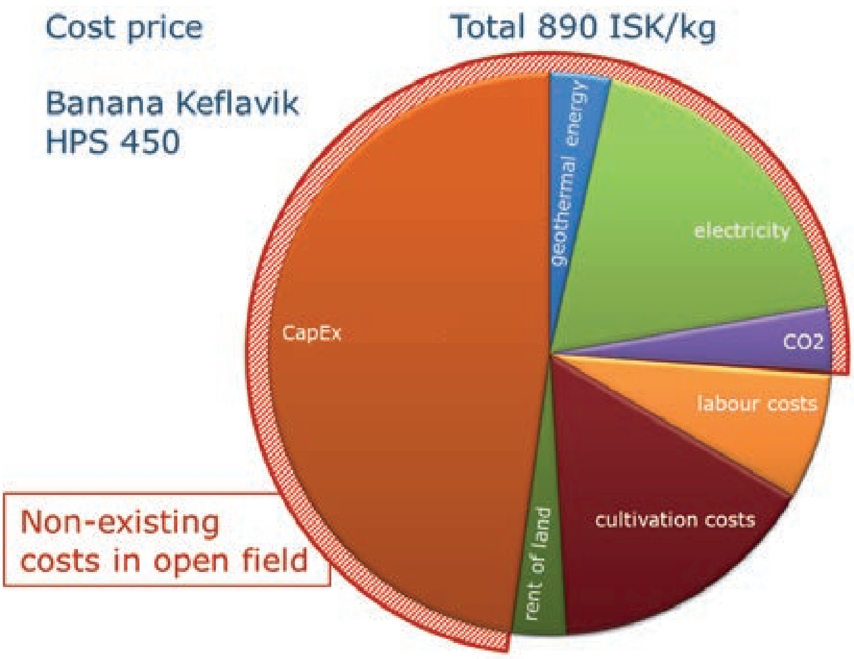

Figure 3 *Distribution of costs in for banana grown in a greenhouse with an HPS lamp at an intensity of 450 micromol/m² s.*

Thus, results indicate that in the domestic market there is a potential for profitable business cases for most fresh crops grown in high tech greenhouses, however, not for indoor factories, for which high CapEx and high amount of electricity needs are the main bottlenecks.

A more detailed sensitivity analysis has indicated that there is a group of products (rice, avocado, banana, potato, wheat) for which, their low productivity per unit area and their low market price excludes them from any possible chance of making a profitable business case. However, there is another group, represented by crops with a much larger productivity per unit area (tomato, lettuce and sweet pepper), thanks to their much larger water content, for which profitability is mostly hampered by the high airplane transport costs to the different markets due to their relatively short shelf-life. Should much lower transportation costs be obtained, more positive combinations would be found. Even more combinations could become positive for these products if we assume a potential boost in production and a decreased use of resources by use of AI algorithms during crop production. The former results mainly apply for greenhouse production. Indoor farms can only be profitable in some crops and markets which would pay a much higher price of an indoor farm product, perhaps due to the absence of any traces of chemical in these products.

1 Introduction

Iceland is well known for its astonishing natural beauty with breath-taking landscapes, the power of nature, its cultural heritage, and its winter darkness.
One can hardly think of this country as a key player in the world horticulture market and yet, there are many reasons to think that this would be possible: this precious land has abundance of some of the factors that can enable protected environment vegetable production, if the right technology is used:

- First, there is abundant empty land. Iceland has an area of 103.000 km^2 and a population of “only” approximately 357.000 people, which makes it the lowest densely populated country in Europe. As a matter of fact, Reykjavik, the capital and its surrounding home two thirds of the total population. That leaves a lot of almost empty land. Of course, since the island is very volcanically and geologically extremely active, this rules out many areas, but there are still enough regions with a lower activity which could be used for intensive horticulture.
- Despite of its high latitude, Iceland has a temperate climate, thanks to the natural stove that the gulf stream represents ensuring generally higher annual temperatures than in most places of similar latitude in the world. Despite its proximity to the Arctic, the island's coasts remain ice-free through the winter.
- Abundance of cheap green energy: about 85% of the total primary energy supply in Iceland is derived from domestically produced renewable energy sources. This is the highest share of renewable energy in any national total energy budget. Geothermal energy provided about 65% of primary energy in 2016, the share of hydropower was 20%, and the share of fossil fuels (mainly oil products for the transport sector) was only 15%. When focussing on electricity, renewable energy provides almost 100% of production, with about 73% coming from hydropower and 27% from geothermal power.
- Abundant and cheap high quality water.

On the other hand, the latitude of Iceland makes light levels to be extremely low during half of the year (autumn and winter) and the relatively low (due to frequent cloudiness) the other half. This makes the use of artificial light essential, for year round production of vegetables. Nowadays, the disruption on the market of LED technology is going to become a game changer in extending the use of artificial lighting in greenhouse operations all over the world.

Finally, one might think of limited labour availability as a bottleneck, but recent developments in AI and robotization and automation, show clearly that the high dependency of human labour for both greenhouse management and crop labours is going to decrease drastically in the next decade.

Thus, with plenty of available land, cheap and abundant green energy and water, AI and automation taking over humans for most tasks, growing vegetables in protected environment, even if large amounts of electricity for lighting (and some extra geothermal heat for heating) and high tech facilities are required, would seem in first sight, as an economically and technically feasible business in Iceland now and, certainly more, in the coming years. This would lead to think that national food security is already largely ensured for most basic vegetable commodities. However, this is not the case. Statistics show that Iceland is self-sufficient for dairy and meat, but not for vegetables and fruits (Figure 4). In fact, the fraction of vegetables that is locally produced is mostly roots and tubers and brassicas, which are produced in the favourable season in open field, and not in greenhouses, whereas products for fresh consumption (fresh vegetables and fruits) are still largely imported, representing typical greenhouse products half of the imported share (Figure 5).

But going one step further, and considering the challenges that vegetable production is facing in many world regions due to climate change (water scarcity, extreme weather episodes, fires, etc.) and the effect on food chains of the coronavirus pandemic, the question that arises is:

- **Is it feasible to produce vegetables on a giga scale for the international market in Iceland?”**

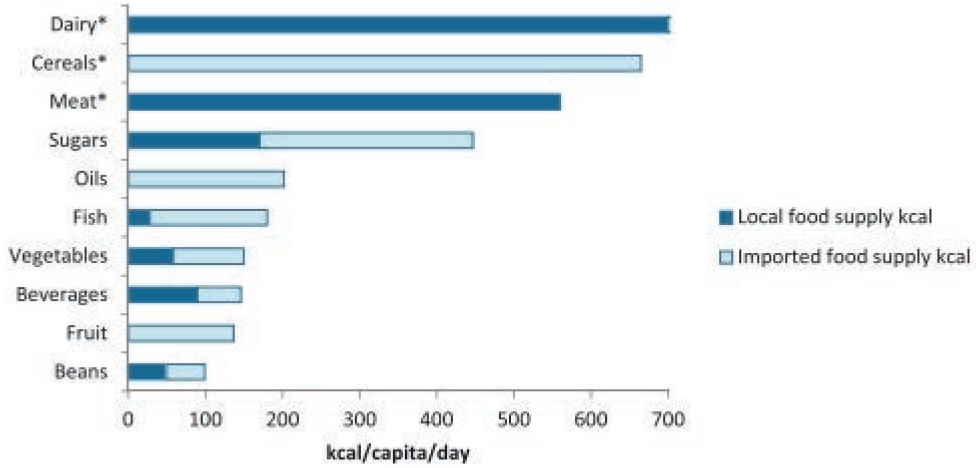

Figure 4 *Imported food (lighter color) and locally produced food (darker color) for ten food categories in Iceland. For each food category, kcal supply was multiplied by import proportion and local food proportion. The top three categories, marked with *, represent 58% of the overall calorie supply, and we considered the potential for increased local production potential for those currently imported. Data for calculations from: FAO-Food balance sheet (2012).*

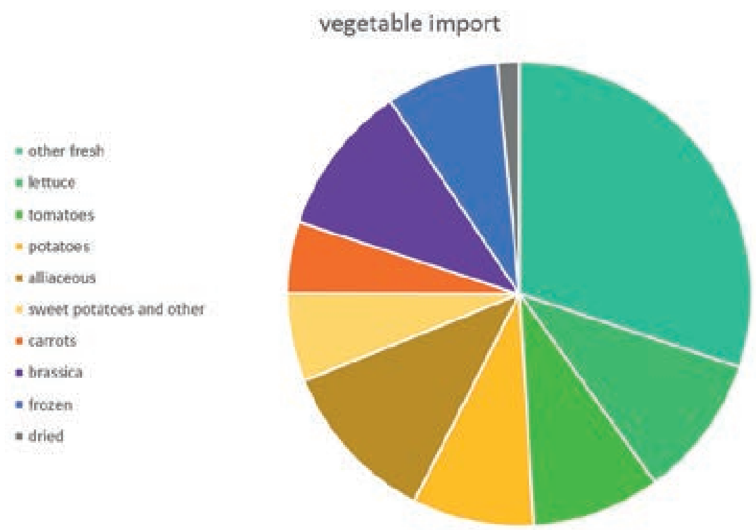

Figure 5 *Vegetable import in Iceland (2018, 2019). Source: https://trendeconomy.com/data/h2?commodity=07&reporter=Iceland&trade_flow=Export,Import&partner=World&indicator=NW,TQ,TV&time_period=2018,2019*

- **Would such giga factories be able to play a major role in feeding the world, not just with fresh vegetables and fruits but also with more caloric vegetal commodities?**

The present work aims to quantify the potential of a large vegetable and/or fruit production facilities (giga vegetable factory) in Iceland based on the local Icelandic resources and the global market. Two main topics will be addressed:

1. What vegetables and/or fruit can be supplied to the international market on a giga scale? Where are these markets located? What will be the selling price of these products? What will be the transport costs to this markets?
2. What vegetables and/or fruit can be produced on a giga scale with a high level of automation? How will such a giga factory design have to look like? What will be the capital and operational costs? What will be the critical production factors? What can be the impact of AI and automation on the cost benefit balance?

All vegetable and fruit products which can be grown indoors are considered after which the potential ones are determined by a set of criteria (crop selection tool). The giga factory design is done for Iceland but the model will be flexible to be used for other locations in the world with similar climate conditions (e.g. Greenland).

2 Approach

2.1 Product selection

For the product selection, a simple crop selection tool was developed. First, a list of pre-candidate crops was agreed with Earth 2.0 which included major vegetable crops, fruits and other major crops in human nutrition (Table 8).

Table 9
List of pre-candidate crops.

Plants	
Tomato (standard)	Onion
Cherry tomato	Rocket
Cucumber	Banana
Pepper	Mango
Eggplant	Avocado
Squash	Grapes (table)
Chilli pepper	Oranges
Lettuce	Lemons
Strawberries	Papaya
Okra	Passion fruit
Cabbage	Parsley
Spinach	Dragon fruit
Water Melon	Sweet potato
Carrot	Broccoli
Green bean	Artichoke
Raspberry	Asparagus

A number of constraints have been defined, which are relevant for the crop selection for protected cultivation in Iceland. The values assigned to each constraint and for each crop have been obtained from a large number of literature and internet sources. The values for each constraint are then normalized in a 1 to 10 scale. High values are desired for each constraint. This is the list of constraints and the explanation for it:

- Harvest index: it measures the percentage of the total biomass (%) in this plant which is harvested and commercialized.
- Space and time efficiency: it measures the average yield of this crop when grown in a high tech greenhouse per unit area and unit time (kg/m^2 day).
- Experience with the crop in protected cultivation: it measures the relevance and commercial experience in cultivation each crop in greenhouses.
- Suitability for mechanization and automation of crop operations: it measures to which extent it is possible to substitute human operation by machines and robots in performing crop tasks.
- Degree of suitability for soilless cultivation: it measures how much commercial experience is available on the soilless cultivation of each crop.
- Labour independence: it measures the intensity of human labour (hours/year) required to grow each crop in a greenhouse
- Speed at which first harvest is attained: it measures the period (days) that it takes on average to obtain harvest from each crop in a greenhouse environment.
- Tolerance and resistance to pest and diseases: it measures the level of tolerance and resistance of commercial cultivars of this crop to pest and diseases in a greenhouse environment.
- Post-harvest life: it measure the average shelf life of each crop.
- Weight versus value: it measures the prices per gr of wet biomass of the harvested product
- Demand on the export market
- Nutritional density: it is measured as the sum of the dry matter content and calories in 100 gr of product.

The following table on the next page shows the scores obtained for the list of pre-candidate crops after normalizing the values from 1 to 10.

Table 10

Scoring of pre-candidate crops on the different indicators.

	Constraint	Harvest index	Space and time efficiency (Yield/(Space*Period)	Experience in climate controled environments	Suitability for mechanization and automation	Degree of suitability for soiless cultivation	Labour independence	Speed at which first harvest is attained	Tolerance (resistance) to pest and diseases	Post harvest life	Weight versus value	Demand on the export market	Nutritional density
Tomato (standard)	1	6.0	8.8	10.0	5.0	10.0	4.1	7.4	8.0	2.6	0.9	7.0	1.3
Cherry tomato	2	6.0	5.3	10.0	5.0	10.0	1.0	7.4	8.0	2.6	0.9	7.0	1.3
Cucumber	3	5.5	9.7	10.0	7.0	10.0	1.7	9.0	5.0	1.8	0.7	7.0	1.0
Pepper	4	6.0	3.8	10.0	6.0	10.0	5.8	7.3	9.0	4.0	1.3	7.0	1.0
Eggplant	5	7.5	5.6	9.0	7.0	10.0	5.6	9.0	5.0	2.5	1.0	7.0	1.6
Squash	6	6.0	10.0	9.0	6.0	10.0	2.4	9.0	6.0	1.8	0.9	7.0	1.2
Chilli pepper	7	5.0	1.8	8.0	6.0	10.0	3.3	9.0	9.0	4.0	10.0	5.0	2.4
Lettuce	8	9.5	8.7	10.0	10.0	10.0	5.1	10.0	9.0	2.5	0.7	7.0	1.0
Strawberries	9	4.0	2.0	8.0	8.0	10.0	2.8	9.0	7.0	1.3	2.3	7.0	2.0
Okra	10	2.0	1.0	1.0	1.0	10.0	8.2	7.7	5.0	1.7	2.0	6.0	2.0
Cabbage	11	6.5	2.4	2.0	7.0	10.0	8.8	9.0	7.0	10.0	0.2	7.0	1.6
Spinach	12	8.0	2.6	5.0	10.0	10.0	9.6	9.0	7.0	1.8	2.4	6.0	1.4
Water Melon	13	9.0	3.2	8.0	8.0	10.0	9.2	7.7	5.0	2.5	1.7	7.0	1.9
Carrot	14	6.0	1.4	3.0	10.0	5.0	10.0	9.0	5.0	4.0	0.3	7.0	2.5
Onion	15	7.0	1.3	3.0	10.0	7.0	10.0	7.3	5.0	10.0	0.3	4.0	2.5
Rocket	16	9.0	1.3	7.0	10.0	10.0	9.9	9.0	6.0	1.3	3.3	3.0	1.6
Banana	17	4.0	1.4	8.0	6.0	7.0	9.4	4.4	3.0	1.0	0.7	5.0	5.0
Mango	18	1.0	1.2	6.0	7.0	2.0	9.9	1.0	4.0	2.5	1.2	8.0	3.5
Avocado	19	1.0	1.1	2.0	7.0	2.0	9.9	1.0	4.0	4.8	2.3	8.0	10.0
Grapes (table)	20	3.5	1.0	7.0	6.0	8.0	8.7	1.0	5.0	6.7	1.5	7.0	3.9
Oranges	21	6.0	1.3	3.0	8.0	4.0	10.0	2.0	2.0	6.7	0.5	7.0	2.8
Lemons	22	6.0	1.3	3.0	8.0	4.0	10.0	2.0	2.0	4.8	2.5	7.0	1.7
Papaya	23	4.5	1.3	6.0	3.0	8.0	9.6	5.1	6.0	1.5	2.3	7.0	2.6
Passion fruit	24	5.0	1.1	3.0	2.0	6.0	9.8	6.7	4.0	3.5	1.0	7.0	5.4
Aromatics (Parsley, mint, coriander, etc.)	25	7.0	4.1	7.0	10.0	10.0	9.9	7.7	9.0	1.3	8.3	7.0	2.1
Dragonfruit	26	5.0	2.0	2.0	2.0	8.0	8.8	2.0	5.0	4.8	1.0	4.0	2.9
Sweet potato	27	7.5	1.3	5	6	6.5	9.9	7	6	10	1	6	6.5
Broccoli	28	3.75	1	6	8.5	6.5	10.0	7.7	4	1	1.0	5	2
Artichoke	29	6.5	1	6	4	6.5	9.2	7.7	7	1	2.3	5	4
Asparagus	30	6	1	8	8.5	6	9.5	2	3	1.75	4.0	5	1.3
Green bean	31	4	1.6	9	7	10	3.3	9	4	1	6.7	6	1.9
Raspberry	32	4	1.6	7	2	8	2.9	7.4	8	1	4.4	7	3.1

The final score for each crop is obtained by multiplying the score of each constraint by weighing factor an summing the resulting value for each constraint. The sum of all the weighing factors is 1. To account for different perspectives on the relative importance of each constraint. In this case, 9 different persons from both Wageningen University and Research greenhouse horticulture and Earth 2.0 proposed their own weights. Then, final scored were averaged and a final list of 8 crops selected. This list was composed of the following crops:

- **Tomato, lettuce, sweet pepper, potato, rice, wheat, avocado, banana and raspberry.**

2.2 Market selection

After a limited selection of typical and non-typical greenhouse products (see section 2.1), we have identified the possible markets for the fresh produce from Iceland. For this market selection, we used various indicators (Table 10) that give insight into the relevant market developments and the attractiveness of the market. The indicators included in the selection model are the following:

- Apparent availability of the produce in the country (tonnes): Production plus import. Exportation is not considered to give a more realistic image of the importance of a country in terms of a dominant trading position. E.g. highlighting the importance of some trade hubs.
- Development of the apparent availability (%): Development based on the last 10 years.
- Import price (USD/ kg): The price of the produce based on the imported value divided by the imported quantity.
- Import quantity (tonnes): The volume imported is based on a 3 year average.
- Import development (%): The development of imported volume in the past 10 years.
- Gross Domestic Product (USD per capita): The GDP per capita.
- Cost of cross border trade (USD): The average costs of importing a container in the country.

WUR has access to the various data sources that provide data on these indicators, see Table below. In our model we normalized the values and constructed a ranking for every product selected. The model provides us a ranking of all countries in the world (n=186), for this study we have selected only the top 8 countries for each product for further analysis.

Table 11
Market selection indicators.

Indicator	Weight	Definition	Source
Apparent availability	Low	Average over last 3 years	FAOStat
Availability development	Low	Yearly, based on 10 years	FAOStat
Availability per person	High	Calculated consumption per head population	FAOStat
Import price	Very high	Price in USD per ton	UNComtrade
Import quantity	Very high	Average over last 3 years	UNComtrade
Import development	Fairly high	Yearly, based on 10 years	UNComtrade
GDP	High	Insights on the ability to buy at high prices	World Bank
Cost of cross border trade	Fairy high	Costs of trading across borders	World Bank

This approach provides insights in 8 products and 8 geographical markets. Many of the identified markets are based in Western Europe. This is to be expected since in those countries people have the most serious buying power. The market prices are rather high and it is relatively easy to do business. Besides, some of the interesting markets are based in Eastern Europe (e.g. Slovenia), often supplied by western European traders.

2.3 Data collection

2.3.1 Investments costs

All the investment costs have been obtained from the publication “Quantitative information on Dutch greenhouse horticulture 2019” from Raaphorst *et al.* (2019). This publication is the most reliable source of information the estimate investment costs for high tech greenhouses in the world. For the indoor farm case, the capex has been obtained from the report “Vertical Farm 2.0: Designing an Economically Feasible Vertical Farm - A combined European Endeavor for Sustainable Urban Agriculture” by Zeidler *et al.* (2017).

2.3.2 Market and transport prices

For the markets included in the shortlist, we have collected relevant wholesale price information. Main data sources for market prices are the United States Department of Agriculture (USDA), the German Federal Office for Food and Agriculture (BLE), FAOStat provided wholesale and producer price information and various other informal sources that together contributed to the overview of prices (min, max and average) and in some cases also the seasonality, see Annex 1). For most products an official wholesale prices are available, in other cases we used a farm gate price. However in all cases we refer to price agreed between farmer and buyer. If not, we mention this explicitly.

We considered to main types of transportation, sea freight and airfreight:

- The costs for sea freight have been considered from Reykjavik to various destinations in the world. In some cases, we had to consider 2 transportation legs. One by ship to the main port on the (e.g. European) mainland and then a second transpiration leg by truck to the final destination further away in central Europe. For both legs, we considered Full Container Loads (20 ft; refrigerated). The information has been collected from the website worldfreightrates.com/freight and the transport company Hapag Loyd for several destinations. It provides detailed information on various types of transportation and related costs. All transportation prices are transformed to a price per kilogram based on the typical loading practices of each product.
- For airfreight, we used proxies to determine the price since forwarders were not willing to provide information. In general a price of 1 USD per kilogram of fresh produce, including forwarding and clearing from Iceland to various destinations in Europe. For more far away market we used a different proxy that reflects the price of airfreight based on our expert knowledge.

Together this composes a total costs price that should allow the producer to make a reasonable profit considering the calculated cost of production.

Of course, market prices fluctuate heavily throughout the year and per passed on supply and production conditions during the season. If supply is affected by unfavourable wheatear in the key production areas, prices are often higher for other suppliers.

2.3.3 Import levies

Information on relevant import levies has been obtained from Market Access Map from the International Trade Centre (ITC) in Geneva[1]. It provides insight in related customs tariffs, tariff rate quotas, trade remedies, regulatory requirements and preferential regimes applicable to the products studied using the Harmonized System. The Harmonized System is a standardized numerical method of classifying traded products. It is used by customs authorities around the world to identify products when assessing duties and taxes and for gathering statistics. The HS is administrated by the World Customs Organization (WCO) and is updated every five years. Import levies are often taxed *ad valorem*, so this means the amount to be paid is based on the value of the transaction. Or in some case there is also an applied tariff (e.g. fee per kg). For example in the USA when importing bananas, raspberries or avocados.

1 https://www.macmap.org/

2.4 Synthesis

After collection of all data we compared the calculated costs price per kg (or unit) produce to the possible revenues that can be obtained in the (foreign) markets. This has to lead to a positive profit margin in order to provide a realistic business case. For the this calculations we used to most favourable cost price calculated.

3 Climate data analysis

Three climates data sets corresponding to three potential locations in Iceland for the location of the new giga factories for vegetable production were obtained and provided by Earth 2.0: Keflavik Airport(Latitude: 63.98; Longitude: -22.6), Eyrarbakki (Latitude: 63.86; Longitude:-21.15) and north of Akureyri (Latitude: 65.68; Longitude: -18.09). The weather data sets for the different Icelandic locations corresponded to three consecutive years (2017, 2018 and 2019). Therefore, it was decided to generate a typical meteorological year (TMY) with the three data sets, to gain more representability of the data. The data were available on an hourly basis. In the data from Eyrarbakki, there were a large number of gaps, especially in the 2019 data set. Different interpolation techniques were applied to fill the smaller gaps periods in 2017 and 2018, while the 2019, with much larger gap periods which accounted to more than 2000 missing data, often in periods of several days, was discarded . In the absence of at least three years for Eyrarbakki, it was decided not to build a typical meteorological year, but to analyse years 2017 and 2018 and investigate whether large differences between both year were observed.

The optimum design for a greenhouse design is strongly influenced by the local climatic conditions. The day length of Iceland oscillates very drastically between the two solstices, given its very high latitude. It goes from virtually no night time hours in the summer solstice in June, to virtually now sunshine hours during the winter solstice in December. In Iceland, the shortest day in winter is only 5 hours long; the longest day is 20 hours (Figure 6).

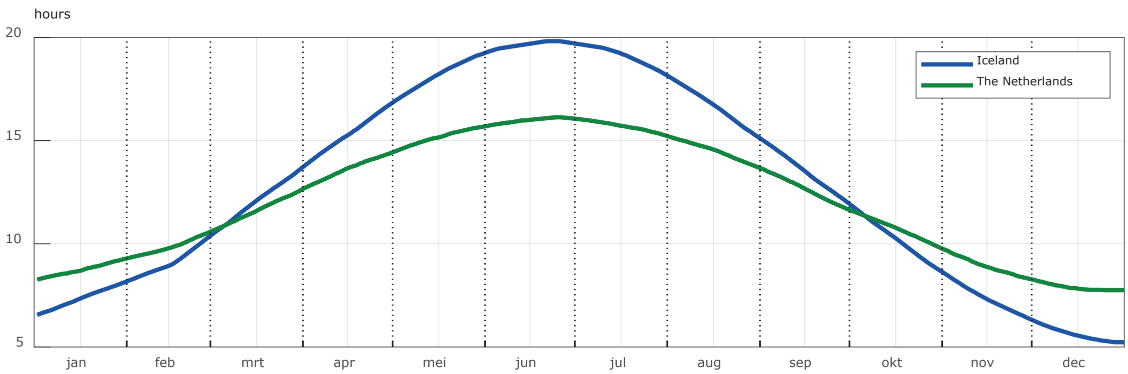

Figure 6 *The course of day length in Iceland and in The Netherlands.*

3.1 Solar radiation

Solar radiation is the most essential parameter determining the amount of dry matter that can be produced by a crop. Unfortunately, the obtained weather data sets do not include directly measured solar radiation data but a cloud factor instead, therefore, the extra-terrestrial solar radiation was obtained for each latitude/longitude and was corrected using the cloud factor data. Data for a TMY obtained for Bleiswijij (The Netherlands) are also included (magenta dotted line) as a reference. The differences on the sum of daily solar radiation (MJ/m^2) between Keflavik, Eyrarbakki and Akureyri are, as expected for such small geographical distance, relatively small, and in general, values are much smaller during the course of the year than in Bleiswijk . Obviously, the time series available is too short to state with statistical significance that Eyrarbakki or Akureyri are sunnier locations than Keflavik. It could be safely said, however, that from the point of view of radiation availability, thet three locations show no significant differences, since the yearly radiation sums are extremely similar for the two locations , with a slightly higher radiation for Eyrarbakki (Figure 3), differences occurring mainly in the months of May, June and August (Figure 7).

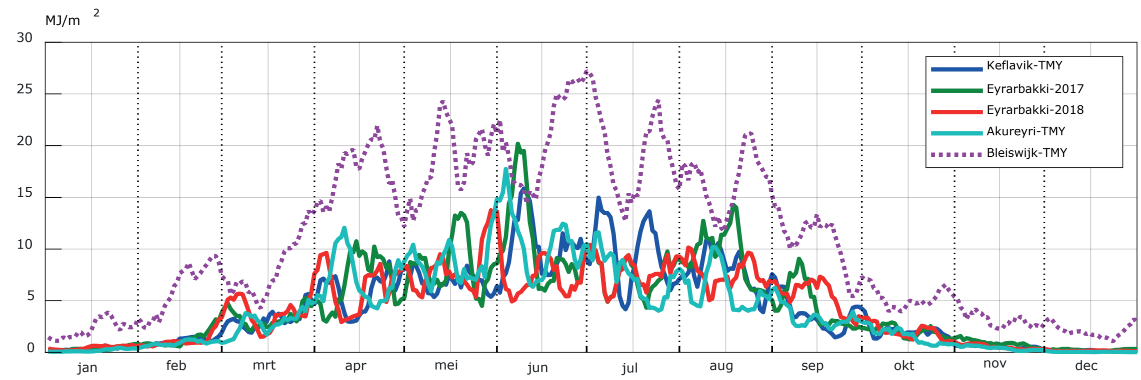

Figure 7 *Daily radiation sum (MJ/m²) for a TMY Keflavik, Eyrarbakki (2018 and 2019) and a TMY in Bleiswijk (The Netherlands). For better visualization, the data were smoothed by a 7 days moving average filter.*

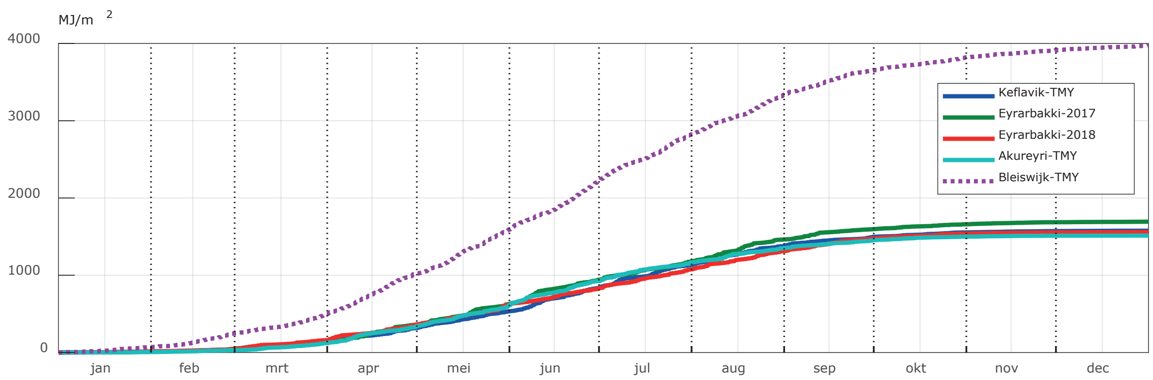

Figure 8 *Cumulative radiation sums (MJ/m²) for global radiation for a TMY Keflavik, Eyrarbakki (2018 and 2019) and a TMY in Bleiswijk (The Netherlands).*

The yearly sum for the TMY in Keflavik is is around 1.57 GJ/m², 1.7 GJ/m² and 1.55 GJ/m² for Eyrarbakki-2017 and 2018 respectively and 1.51 GJ/m² for the TMY in Akureyri, all of them consistently lower than the 4 GJ for a TMY in The Netherlands (Figure 8). Because of this, potential yield for vegetable production in Iceland is much lower than in the Netherlands, unless a large amount of artificial light is used year round

3.2 Temperature

Due to the lower radiation intensities most of the year in Iceland, outside temperatures (mean, maximum and minimum values) are also lower than in The Netherlands (Figure 9, Figure 10 and Figure 11).

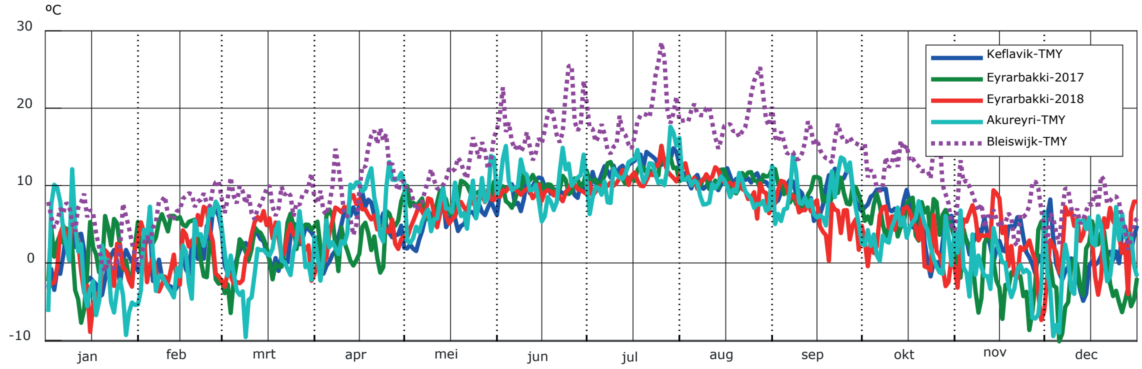

Figure 9 *Daily mean outside temperature (°C) for a TMY Keflavik, Eyrarbakki (2018 and 2019), a TMY in Akureyri and a TMY in Bleiswijk (The Netherlands).*

Mean daily temperatures (Figure 9) are extremely similar for the three simulated locations (and for the two simulated years in Eyrarbakki) between May and August. During the cold months, differences become larger. We see quite a variability for Eyrarbakki for year 2018, while 2017 seems more similar to a TMY for Keflavik. If a TMY could have been built for Eyrarbakki, perhaps the observed differences for 2018 could have been minimized. We also see that for Akureyri, there are some colder periods in the winter time than for the other locations. As for the maximum and minimum temperatures, we observe mostly the same trend observed for the mean values. Perhaps we can highlight the fact that temperatures were especially low in Eyrarbakki on year 2017 during November and December and in Akureyri for the TMY. Values in Table 11 are prove of the small difference on temperatures between the three simulated locations in Iceland. Akureyri is slightly colder in winter than Keflavik and Eyrarbakki.

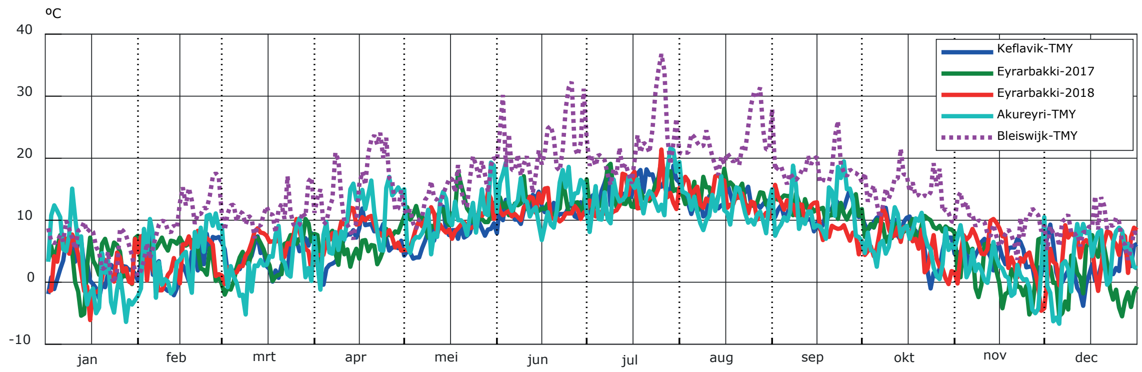

Figure 10 *Daily maximum outside temperature (°C) for a TMY Keflavik, Eyrarbakki (2018 and 2019), a TMY in Akureryri and a TMY in Bleiswijk (The Netherlands).*

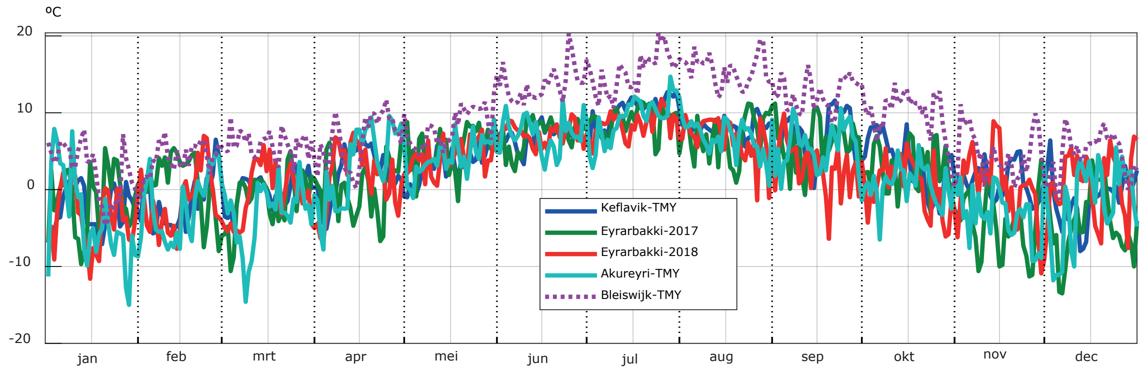

Figure 11 *Daily minimum outside temperature (°C) for a TMY Keflavik, Eyrarbakki (2018 and 2019), a TMY in Akureyri and a TMY in Bleiswijk (The Netherlands).*

Table 12

Summary of maximum, minimum and mean temperatures (mean and absolute values) for a TMY Keflavik, Eyrarbakki (2018 and 2019), a TMY in Akureyri and a TMY in Bleiswijk (The Netherlands).

Location/year	Mean of minimum temperatures (°C)	Absolute minimum temperature (°C)	Mean yearly temperatures (°C)	Mean of maximum temperatures (°C)	Absolute maximum temperatures (°C)
Keflavik/TMY	3.2	-7.4	5.4	7.5	19.8
Eyrarbakki/2017	2.3	-13.5	5.2	7.8	19.8
Eyrarbakki/2018	2.3	-11.6	5.1	7.8	21.4
Akureyri/TMY	1.9	-15	4.8	7.8	21.6
Bleiswijk/TMY	8.6	-4.6	11.6	14.6	36.8

3.3 Humidity

The analysis of daytime humidity values indicates small differences year round for the simulated locations in Iceland, with Keflavik showing slightly higher values than in Eyrarbakki, but mostly, with Akureyri been a much drier location than the other two, even drier in many periods than Bleiswijk (Figure 12). During the night-time period these differences are maintained, being Keflavik more humid than Eyrarbakki and these two, more humid than Akureyri (Figure 13 and Table 12).

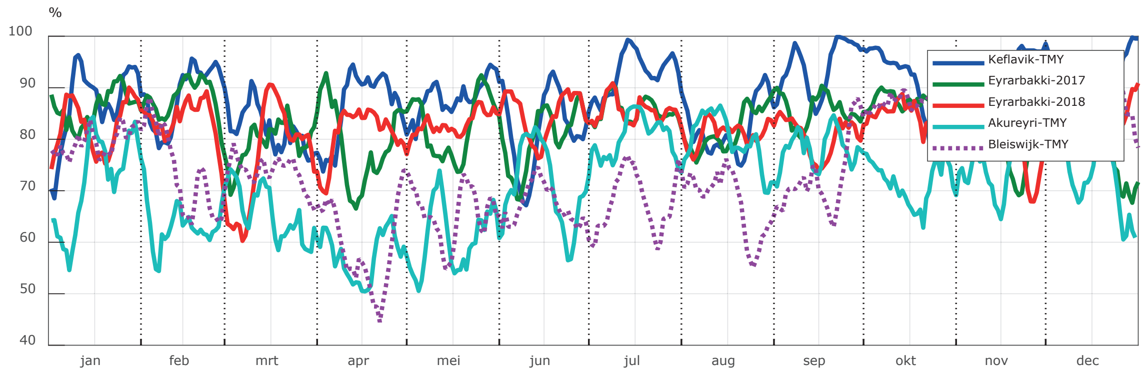

Figure 12 *Daytime mean outside relative humidity (%) for a TMY Keflavik, Eyrarbakki (2018 and 2019), a TMY in Akureryri and a TMY in Bleiswijk (The Netherlands). The data were smoothed by a 7 days moving average. filter*

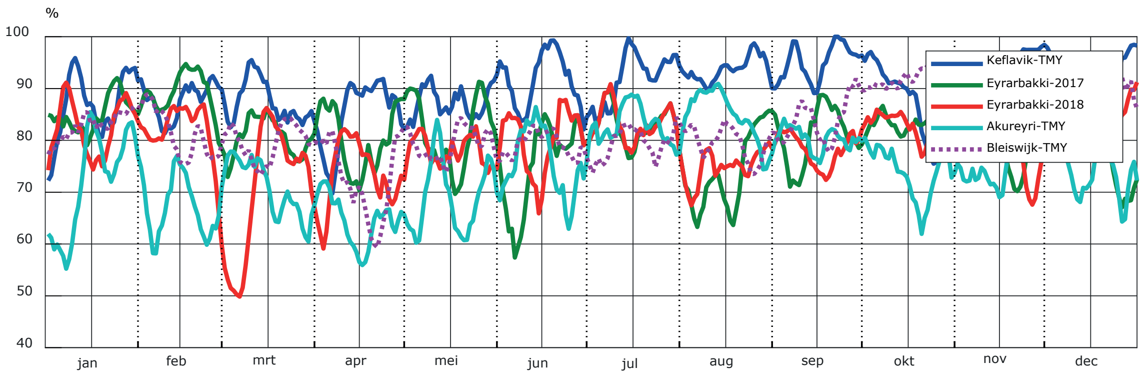

Figure 13 *Night-time outside relative humidity (%) for a TMY Keflavik, Eyrarbakki (2018 and 2019), a TMY in Akureyri and a TMY in Bleiswijk (The Netherlands). The data were smoothed by a 7 days moving average filter.*

Table 13

Summary of maximum, minimum and mean R.H. (mean and absolute values) for a TMY Keflavik, Eyrarbakki (2018 and 2019), a TMY in Akureyri and a TMY in Bleiswijk (The Netherlands).

Location/year	Mean of daytime values (%)	Mean of night-time values (%)
Keflavik/TMY	84.7	89.4
Eyrarbakki/2017	82.9	81.7
Eyrarbakki/2018	82.8	80.3
Akureyri/TMY	70.7	73.9
Bleiswijk/TMY	71.1	84.9

3.4 Wind

Both Keflavik and Eyrarbakki (in the south of Iceland) are very windy, slightly less from June to September, and consistently windier than Akureyri (in the north of Iceland) and similar to Bleiswijk (Figure 14 and Figure 15). The peak hourly values are as high as 25 m/s, which means that wind gusts above 100 Km/h can be expected. This has profound implications in the calculation of the greenhouse structure and on the thermal losses from the greenhouse, which will be higher due to the windy nature of the climate in these two locations.

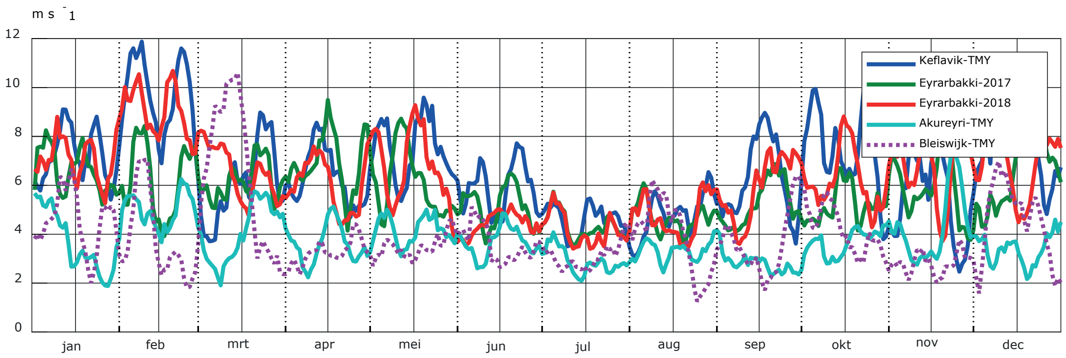

Figure 14 *Daily mean outside wind velocity (m s-1) for a TMY Keflavik, Eyrarbakki (2018 and 2019), a TMY in Akureyri and a TMY in Bleiswijk (The Netherlands). The data were smoothed by a 7 days moving average filter.*

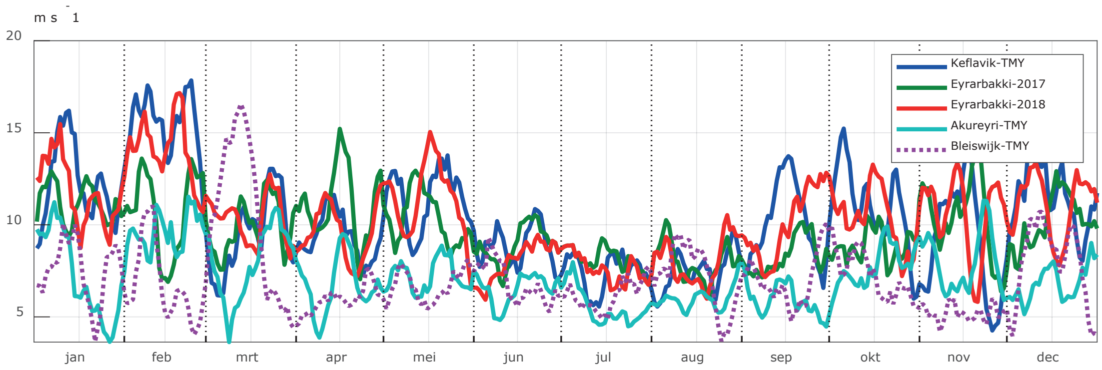

Figure 15 *Daily max outside wind velocity (m s-1) for a TMY Keflavik, Eyrarbakki (2018 and 2019), a TMY in Akureyri and a TMY in Bleiswijk (The Netherlands). The data were smoothed by a 7 days moving average filter.*

3.5 Snowfall

3.5.1 Keflavik

The analysis of the snowfall from the last three complete years (Figure 16, Figure 17 and Figure 18) indicate that between October and May, snow may fall. As a matter of fact, snow fell every analysed year between November and April. In 2019 some months showed a really large number of snow days (16, in March). The maximum accumulated snowfall in a month was around 20 cm, so not too large, and that is the largest in the last 10 years.

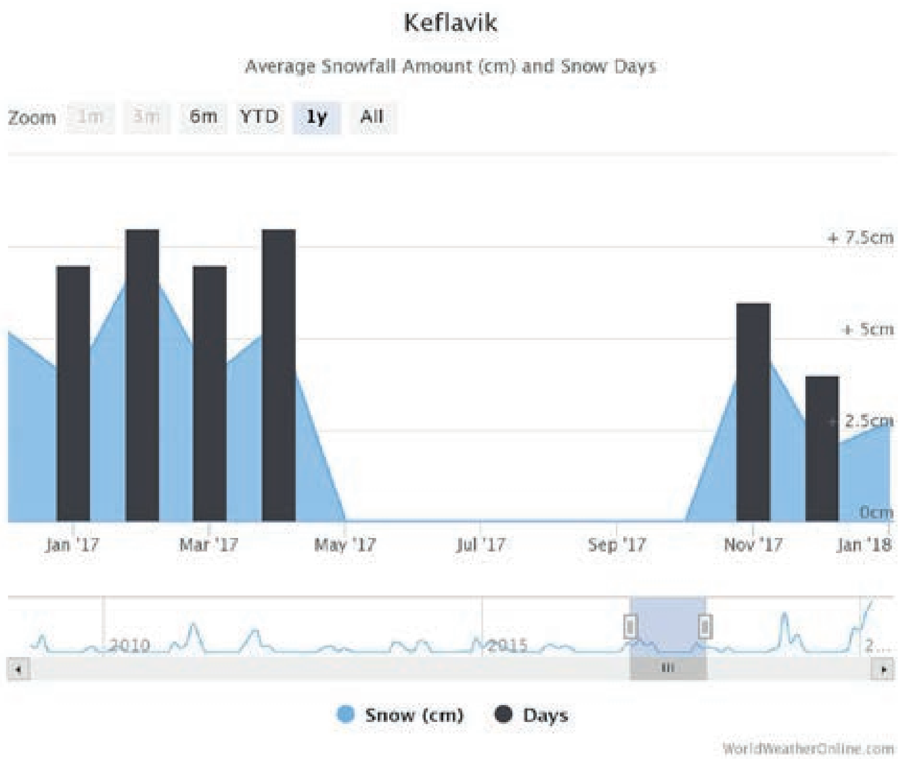

Figure 16 *Monthly snowfall and average number of snow days on year 2017 in Keflavik (Iceland).*

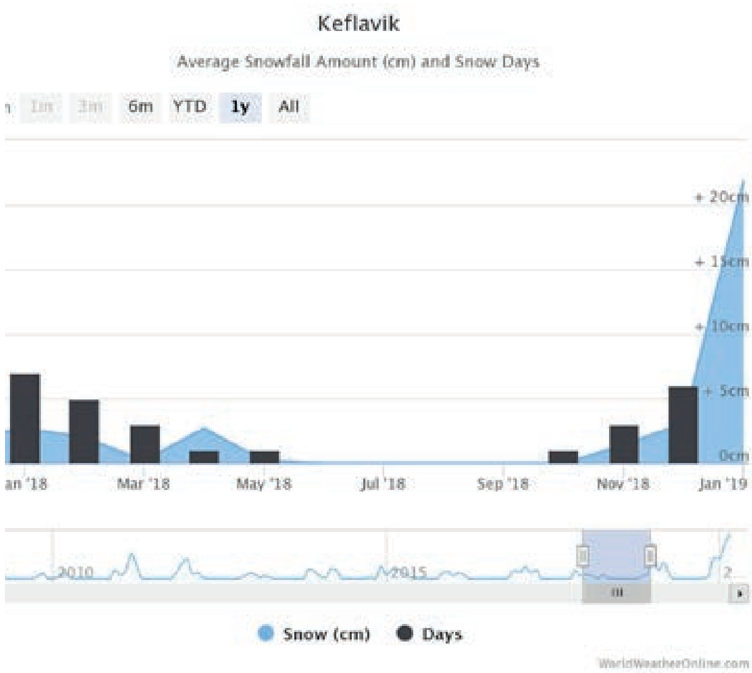

Figure 17 *Monthly snowfall and average number of snow days on year 2018 in Keflavik (Iceland).*

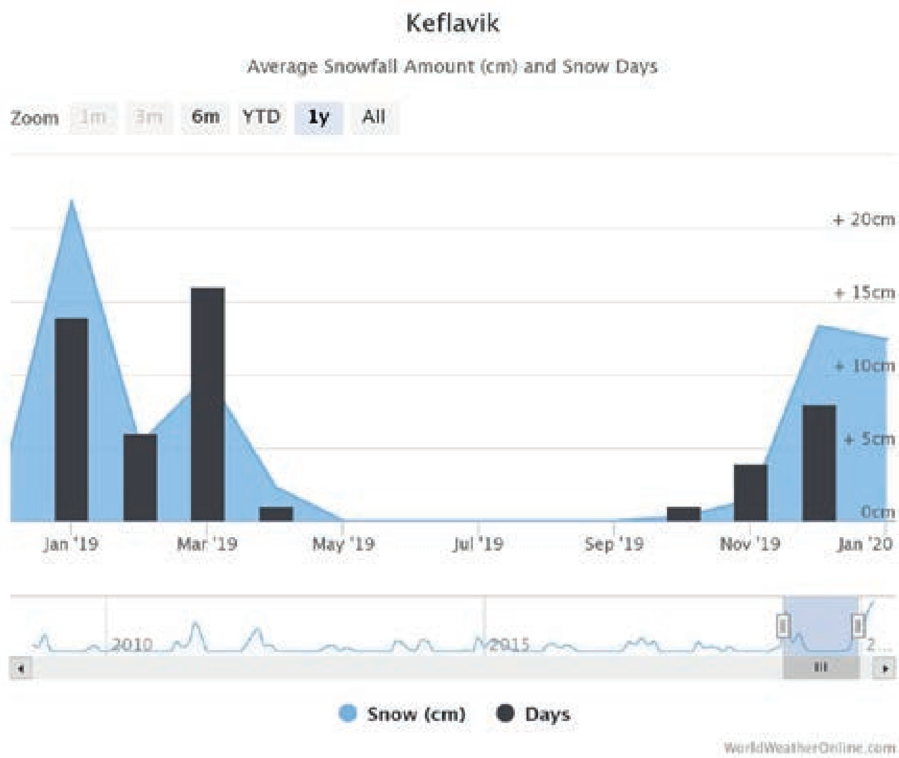

Figure 18 *Monthly snowfall and average number of snow days on year 2019 in Keflavik (Iceland).*

3.5.2 Akureyri

The analysis of the last three years for Akureyri shows that snowfall can be larger than for Keflavik (in December 2019 more than 2m of snow fell in total!), and snow is likely to fall also in June and September (Figure 19, Figure 20 and Figure 21).

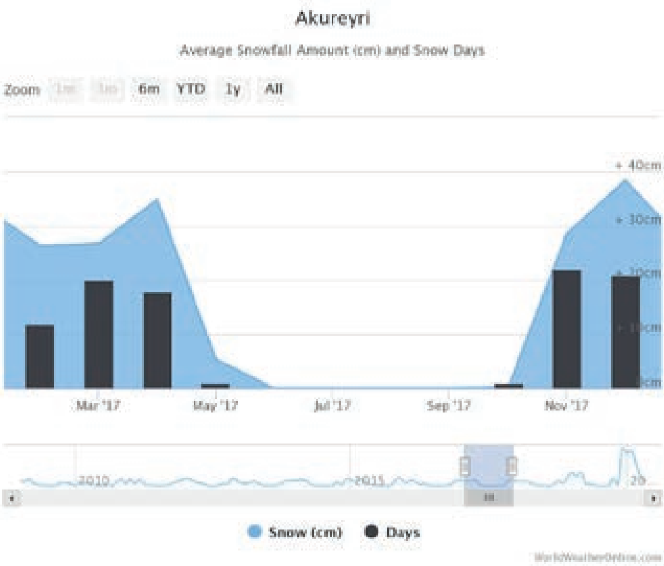

Figure 19 *Monthly snowfall and average number of snow days on year 2017 in Akureyri (Iceland).*

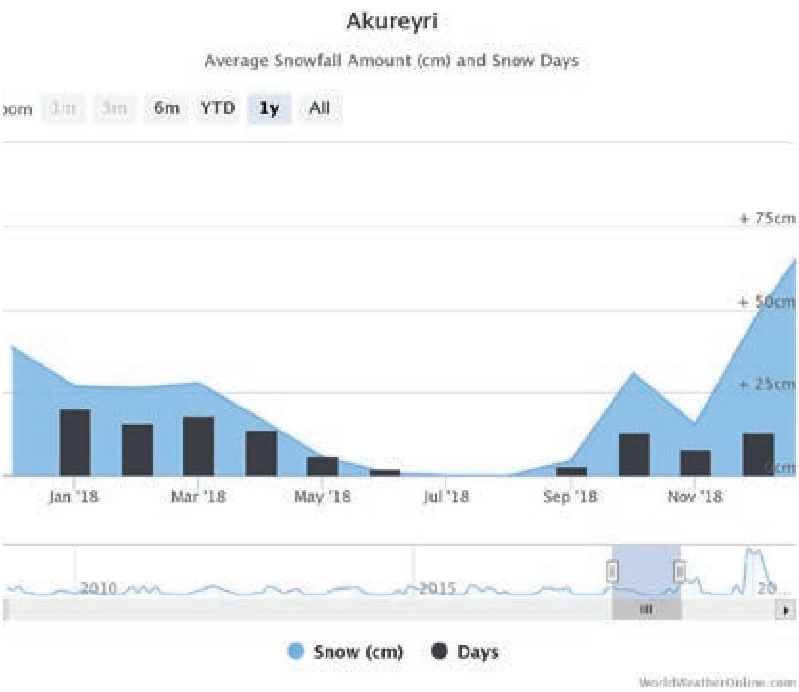

Figure 20 *Monthly snowfall and average number of snow days on year 2018 in Akureyri (Iceland).*

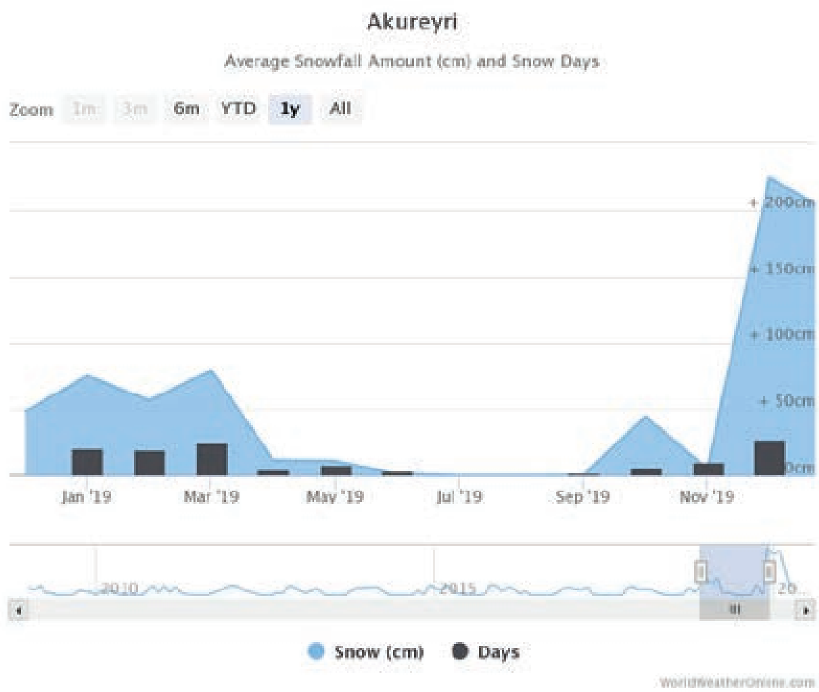

Figure 21 *Monthly snowfall and average number of snow days on year 2019 in Akureyri (Iceland).*

3.6 Boundaries of the passive greenhouse

A quick way of analysing, for a given climate location, which parts of the year greenhouse cultivation can be successfully developed in a passive greenhouse and which require either heating, cooling and/or artificial light, is to plot per month the mean daily radiation versus the mean daily temperature. For that, we need to establish thresholds above or below which, active climate control means are needed. Of course, these values differ depending on the cultivated species, but for the most popular vegetable crops (sweet pepper, tomato, cucumber, aubergine, etc.) acceptable values would be that below an average daily temperature of 12 °C, heating is required, and above 23 °C, active cooling is required. Finally, if daily radiation sum is below 8 MJ m^{-2}, artificial lighting would be needed. For a TMY in Keflavik, as well as in Eyrarbakki and in Akureyri (Figure 22, Figure 23 and Figure 24), heating is required year round, and artificial light is necessary to grow from September to April.

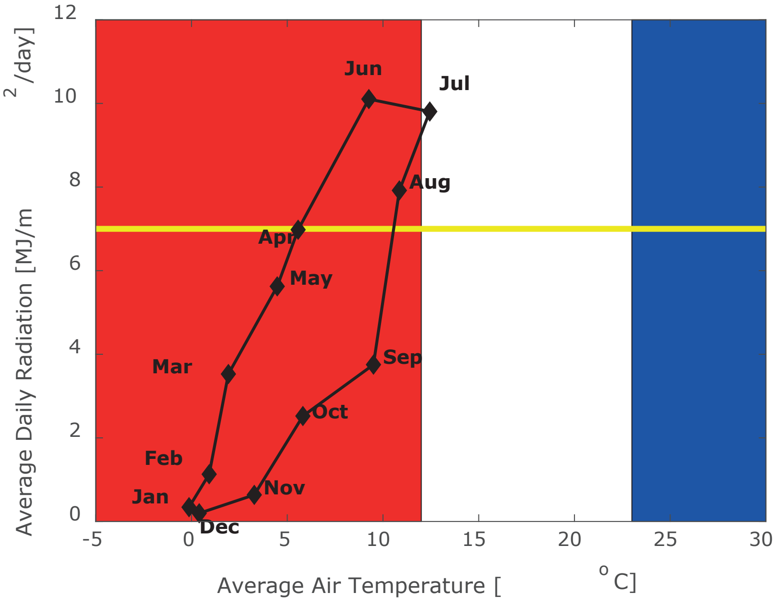

Figure 22 *Average daily values per month (TMY) of radiation sum (MJ m⁻²) and temperature (°C) for Keflavik. The red and blue zones delimit the conditions under which heating and cooling would be essential for successful growth of most commonly cultivated vegetable species. The zone below the yellow line delimits the minimum average daily radiation sum (MJ m⁻²) above which artificial lighting is absolutely required to grow.*

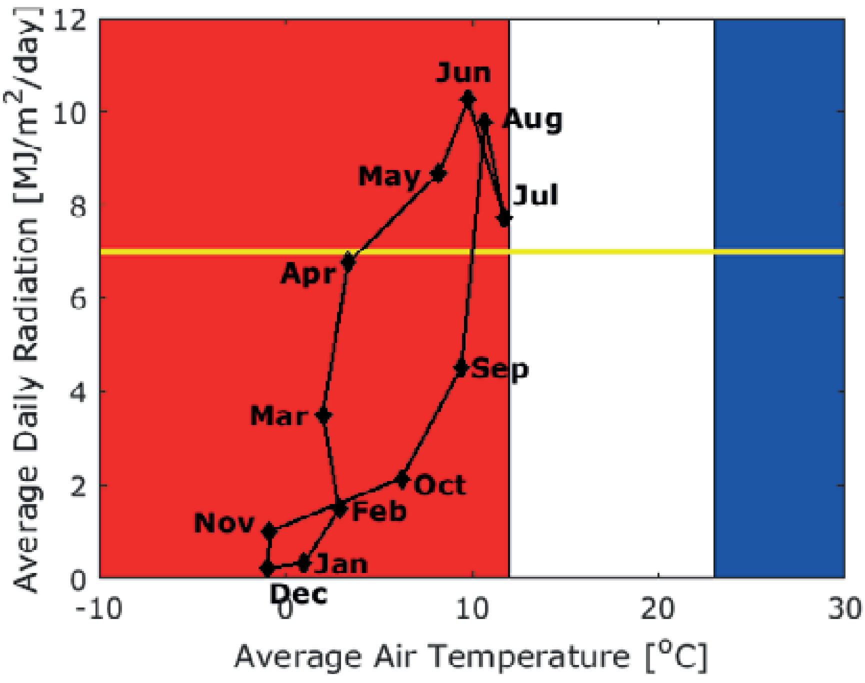

Figure 23*. Average daily values per month (2017) of radiation sum (MJ m⁻²) and temperature (°C) for Eyrarbakki. The red and blue zones delimit the conditions under which heating and cooling would be essential for successful growth of most commonly cultivated vegetable species. The zone below the yellow line delimits the minimum average daily radiation sum (MJ m⁻²) above which artificial lighting is absolutely required to grow.*

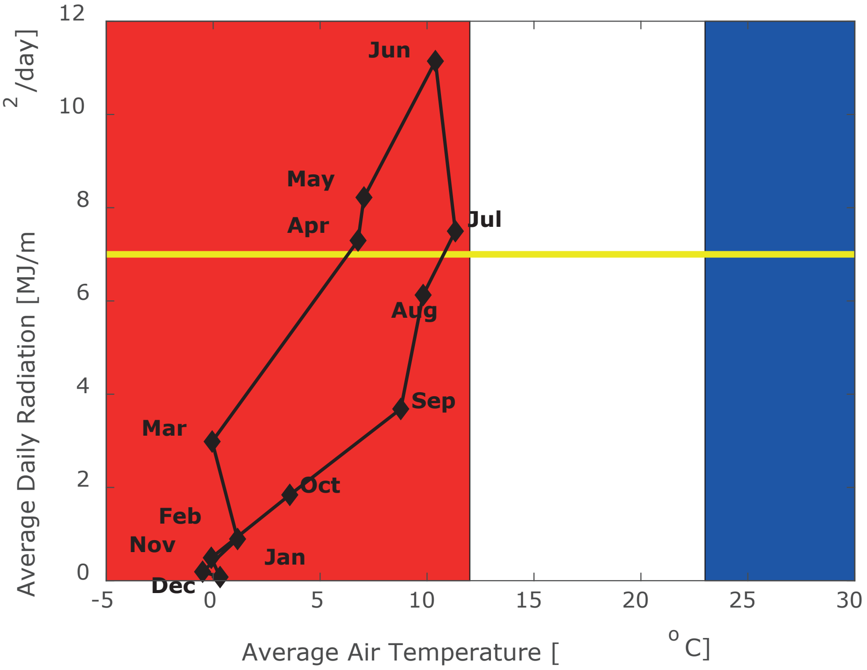

***Figure 24**. Average daily values per month (TMY) of radiation sum (MJ m^{-2}) and temperature (°C) for Akureyri. The red and blue zones delimit the conditions under which heating and cooling would be essential for successful growth of most commonly cultivated vegetable species. The zone below the yellow line delimits the minimum average daily radiation sum (MJ m^{-2}) above which artificial lighting is absolutely required to grow.*

4 Greenhouse design

Iceland, has a cold, dark and windy climate. Luckily, it also has easily accessible low and high temperature geothermal water, which provides enough and sustainable hot water for heating and electricity for lighting.

A greenhouse in Iceland must have an insulating cover, but not extremely insulating, such as double glass, because the snow would not be easily melt. Besides, price of hot water is not very high, so energy saving, although important, is not critical. The cover must also be very transparent too, to allow as much as possible of the limited amount of solar light available. Glass is clearly the best option combining both factors. Regarding the choice between diffuse and clear glass, the cloud factor data indicate a very clear predominance of diffuse radiation over direct radiation. In fact, for the TMY obtained for Keflavik, direct radiation accounts for only 25% of the total radiation reaching the ground (in Bleiswijk, that ratio is close to 50%-50%). Under these conditions, the use of a diffuse glass is less critical and since higher diffusion also involves a loss in overall transmission and a higher price, we have chosen for a standard clear glass in our simulations. The benefit on yield and the small and the effect on decrease in energy use of using a glass with improved transmission, such as glass with AR coatings, has been analysed by making simulations for both a standard glass and a glass with an AR coating.

The best greenhouse design to be covered with glass is the Venlo type. There is a trend to build wider spans in Venlo greenhouses: from traditional span of 4 m to 4.8 m and even wider in some prototypes such as the Winterlight greenhouse (Kempkes *et al.* 2018) to reduce the structural elements and increase light transmission. However, the analysis indicates that some locations in Iceland can be very windy Figure 9, and building the greenhouse with wider spans and less structural elements, would increase the risk on the structure. Therefore, we have chosen to simulate a traditional Venlo with a 4 m span width.

The Icelandic climate is so dark that artificial light is required to grow, not just during the winter months, but year round. The two alternative lighting systems that will be analyzed are HPS lamps and LED's.
To prevent light pollutions, which in principle, is required in Iceland by most municipalities, a blackout screen must be used, which will also reduce the energy use. However, the use of screens in very cold climates with high chances of snow has consequences. As a matter of fact, the most common method for melting snow in high-tech glass-glazed greenhouses is to open the curtain/s, which allows the heat to rise to the peaks of the greenhouse before snowfall. By doing so, the heated air warms the greenhouse glass so the snow melts upon contact. However, if snowfall exceeds the rate of snow melt, snow will begin to accumulate on the greenhouse, forming an insulation barrier and reducing heat loss. Although an insulation barrier is created, the snow contacting the greenhouse glass will melt and run off. Another problem among greenhouse operators who manage gutter-connect greenhouses is bridging. Bridging occurs when snow slides towards the gutter, accumulates and the heat transferred from the gutter melts the snow and creates a bridge between the two greenhouses. In many cases there is not adequate heat exchange to collapse, melt and run or slide off the snow. So how do you prevent bridging? Most recommendations are to place a heating source sideways and under the gutters (Figure 25) to cause the bridge to collapse and melt the snow.

Since the detailed hourly snowfall data are not available, it is not possible to simulate the amount of hours in which the blackout screen will have to be open (totally or partially) to melt the snow. Therefore, simulations have been made with and without the blackout screen. An average number of snowdays will be estimated between October and May and in those days, the energy requirement will be re-calculated assuming a fully open curtain, and an extra energy required to melt the snow, for which an average amount of snowfall based on the available data will be assumed.

Figure 25 *Multi-span greenhouse with a "snow" pipe below the gutters.*

The other consequence of using a blackout screen is that humidity both sensible and latent heat accumulate below the screen. This accumulation was traditionally controlled by opening small gaps on the screen and opening the windows, at the expense of using more energy and creating climate heterogeneity. However, there are other options that can be used (mechanical ventilation dehumidification, heat pump dehumidification, etc.). A particularly simple and efficient solution is to install vertical fans forcing the circulation of air between the upper compartment (with drier and cooler air) and the lower compartment (warmer and more humid). This system will be evaluated in our simulations.

4.1 Detailed set-up used for the tomato simulations

This section includes all the quantitative information concerning the final design and set points used to simulate a greenhouse for both tomato and lettuce production in the two selected locations in Iceland. Since the climate data analysis for both regions does not show significant climate differences the greenhouse design and the set points will be the same for both locations. However, since there are some differences in temperatures, mainly, we will still do simulations for both locations, since the energy requirements will surely be slightly different.

We have simulated a 5 Ha greenhouse. This is approximate the average area of glasshouse company in The Netherlands, which makes this size a very representative case for simulations in Iceland. It has also been assumed that the greenhouse has façade ratio of 1 (square shape). The rest of geometric parameters are summarized in Table 13.

Table 14
Summary of main geometrical parameters of the simulated greenhouse.

	value	Unit
Area	50000	m^2
Façade Ratio	1	-
Gutter height	6	m
Roof slope	23	deg
Orientation*	0	deg
Leakage	0.0001	$m^3\ m^{-2}\ s^{-1}$ per $m^2\ s^{-1}$ wind speed
Façade enabled**	1	factor
Façade U-value***	6	$W\ K^{-1}$
Maximum vent opening angle	60	deg
Window length	1.67	m
Window height	1.2	m
Area per vent****	20	m^2

* This means greenhouse gutter has and East-West orientation
** This means the heat losses through the sidewalls are also simulated
*** Global heat loss coefficient
**** Greenhouse area ventilated by each individual vent

We have simulated two types of glass covers: a standard glass and an improved glass with and AR coating. Their main optical properties of the greenhouse covers (including the effect of the structure) are summarized in Table 4

Table 15
Summary of the optical properties of the two simulated roof covers.

	Standard glass cover	Improved glass with 1 AR coating
Hemispherical transmission (300-400 nm)	0.688	0.64
Hemispherical transmission (400-700 nm)	0.792	0.84
Hemispherical transmission (700-2500 nm)	0.755	0.746
Emissivity	0.89	0.89
Haze	0	0

A typical growing cycle of tomato with artificial lighting was simulated: transplant on September 7th and end of the growing cycle on September 1st of the following year (1 week for crop removal, cleaning, disinfection, etc.).

The most relevant crop simulation parameters can be found on Appendix A.

In practice, the greenhouses in Iceland are heated using geothermal water with a temperature of 80-90 °C. A large hot water buffer is used to store the hot water and different heat exchangers and three way valves are used to control the temperature in the system given the existing conditions and the required set points. The hot water is distributed in the greenhouse using both a primary network of metallic pipes forming a double loop between each two rows, located few cm above the ground and a secondary system consisting on a single pipe per each crop row, which is closer to the canopy. The details of the greenhouse heating system are summarized in Table 15.

Table 16

Summary of the main parameters of the simulated primary and secondary heating systems.

Primary heating system	Value	Unit
Peak heating power	175	W m^{-2}
Hot water buffer volume	120	m^3 Ha^{-1}
Number of pipes*	1.25	-
Pipe diameter	0.051	m
Position	Below the crop	-
Maximum pipe temperature	65	°C
Circulation time	20	min
Secondary heating system	Value	Unit
Number of pipes*	0.625	-
Pipe diameter	0.032	m
Position	Between crop	-
Maximum pipe temperature	55	°C
Circulation time	20	min

* Number of pipes per m of the grow pipe

The simulated blackout screen was a commercial model (Obscura 9950 FR) for which all the physical properties were available after having been measure in our laboratory. The most relevant properties and the set points for the management of this screen are summarized in *Table 16*.

Table 17

Summary of blackout screen properties and set point used for the simulations.

	Value	Unit
Air permeability	$3.7*10^{-7}$	m^{-2}
Hemispherical transmission	0.05	
Emissivity up and down faces	0.81	-
Close below*	5	W m^{-2}
T_{out} maximum**	14	°C
Light pollution prevention	True	
Gap on temperature excess***	2 4	°C/%
Gap on relative humidity excess****	2 4	%/%

* The screen closes whenever solar radiation drops below this value, if the outside temperature** is below the designated value

*** For each excess of greenhouse air temperature of 2 °C over the temperature set point, the screen opens a gap of 4 %

**** For each excess of air relative humidity of 2 % over the rh. set point, the screen opens a gap of 4%

The characteristics of the two types of lamps simulated in the artificial lighting system and the set points are summarized in Table 17.

Table 18
Summary of the main properties the different types of lamps used in the simuations.

Type		HPS lamp	
Power		1000	W
Fraction therm*		0.39	-
Efficiency (400-700 nm)		1.78	μmol J^{-1}
Type		LED	
Power		150	W
Fraction therm*		0.37	-
Efficiency (400-700 nm)		2.9	μmol J^{-1}
	Date	Value	Unit
Position		Above crop	
Hours of light	01-05	14	frac h
	07-09	12	
	14-09	13	
	21-09	14	
	28-09	15	
	04-10	16	
End time		20	frac h
Maximum I_{glob}**		100 175	W m^{-2}
Maximum PAR sum***		18	Mol day^{-1}

* Fraction of the nominal power converted to sensible heat

** Radiation to switch off lamp sections. Number of values equals number of sections

*** When daily PAR sum tops this value, lamps turn off

Vertical fans with a capacity of 20 m^3 m^{-2} h^{-1} were simulated, which were activated simultaneously with the screen.

The heating and ventilation temperature and humidity set points are summarized in Table 18.

Table 19

Summary of temperature set points for control of heating and windows.

	Unit	Date	Hour of the day*/temperature set point	Explanation
Heating temperature	°C	01-03		Below this temperature the greenhouse is heated
		01-04	r-1=18 r+1=19 s-1=19 s+1=18	
		01-06	r-1=16 r+1=18 s-1=18 s+1=16	
		15-08	r-1=20 r+1=20 s-1=20 s+1=20	
		07-09		
		01-10		
		01-11		
Ventilation offset	°C	20-01		Offset from the heating setpoint at which venting starts
		01-03	r-1=1 r+1=1.5 s-1=1.5 s+1=1	
		25-05	r-1=1 r+1=1 s-1=1 s+1=1	
		20-10	r-1=1 r+1=2 s-1=2 s+1=1	
		01-11		
P-band vents	°C		5 15; 20 5	Temperature excess needed for fully opened vents as function of outside temperature

*r is sunrise time and s is sunset time

The relative humidity set point 85%. With a P-band of 0 15;20 5. The CO_2 set point is 700 ppm in the period that comprises 1 hour after sunrise and one hour before sunset. Pure CO_2 is applied in the simulation.

4.2 Detailed set-up used for the lettuce simulations

The simulations for lettuce have been done assuming cycles of 60 days with uniform conditions and a constant photoperiod of 16 h d^{-1}. Lettuce is much colder crop and therefore, the heating set points for the light and dark period were respectively 12/9 °C, 15/12 °C and 18/15 °C for the light and dark period, respectively.

4.2.1 Effect of the cover type on yield and energy use for a tomato crop

The use of a cover with improved light transmission has two major effects to focus the analysis: energy use (both heating and electricity) and final yield. The effect on energy use or heating is minor. In this comparison we have assumed that there is not limitation in the use of the screen due to snow fall and the amount of energy required to melt the snow has not been considered for the moment, either. In addition, a dehumidification system based on the use of vertical fans has been simulated. A more detailed analysis on these equipment and their effect on microclimate, resource use and potential tomato yield will be done later. This is done in this way to prevent an excessive number simulations when, in fact, only the relative differences are relevant in order to choose the right glass type. Both daily energy sum and cumulative values for heating are plotted (Figure 26 and Figure 27), with differences between a normal and an improved glass being imperceptible, in the three simulated locations. The final energy requirements for heating are extremely similar in both Eyrarbakki and Keflavik and slightly lower for Akureyri, which proves that simulating only for Keflavik is representative also for Eyrarbakki. The main reason behind the lower heating requirements in Akureyri despite of the lower temperatures is the lower wind velocities, which decrease much the greenhouse thermal losses. There are virtually no differences in energy required for heating when a glass with improved light transmission is used in this latitudes, due to the small contribution of outside solar radiation, compared with the energy input provided in the form of heating and artificial lighting(Table 19).

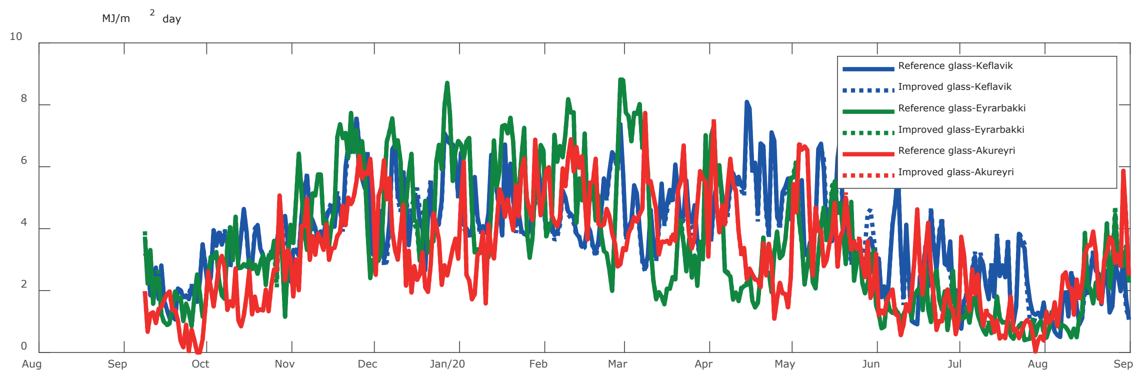

Figure 26 *Daily energy sum (MJ/m² day) required to heat the glasshouses simulated both for a TMY of Keflavik and years 2017-2018 for Eyrarbakki, for both a reference and an improved glass.*

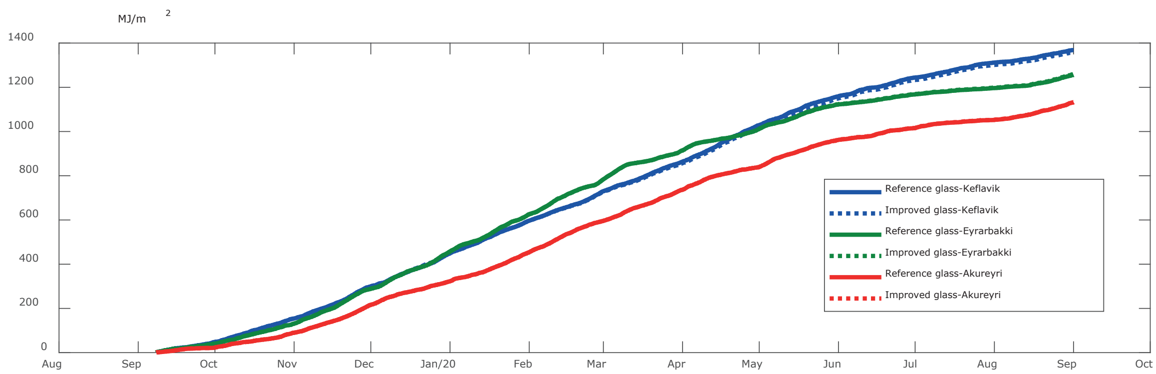

Figure 27 *Cumulative energy sum (MJ/m² day) required to heat the glasshouses simulated both for a TMY of Keflavik and years 2017-2018 for Eyrarbakki, for both a reference and an improved glass.*

The lamps also use an almost similar amount of electricity for artificial lighting under both simulated covers and in the two simulated locations (Figure 28), therefore, the extra amount of sunlight brought into the greenhouse at this very northern latitudes does not lead to a much lower number of hours in which lamps are functioning (Table 19).

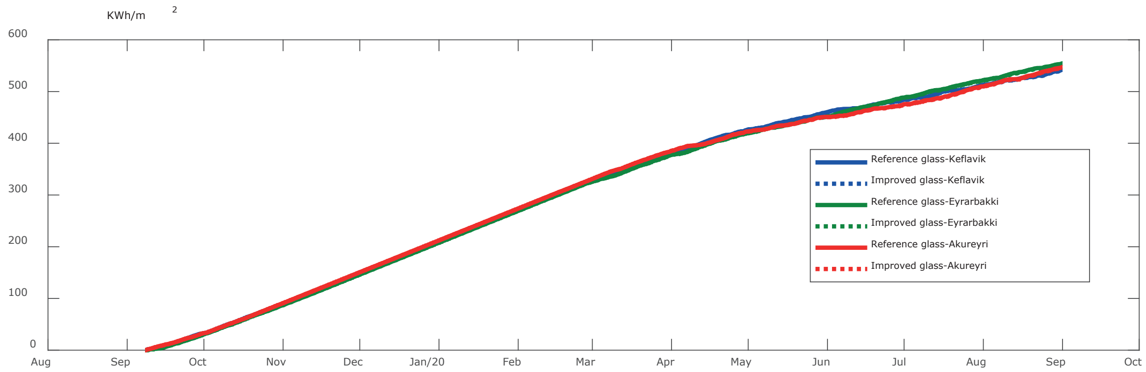

Figure 28 *Cumulative electricity (KWh/m²) used by the artificial lighting system simulated both for a TMY of Keflavik, a TMY for Akureyri and years 2017-2018 for Eyrarbakki, for both a reference and an improved glass.*

Table 20

Summary of energy use for heating and lighting and potential yield when using both a reference and an improved glass in the cover.

	Energy used for heating (MJ m^{-2})	Electricity used for artificial lighting	Hours lamps are on	Tomato yield (kg/m^2)
Reference glass Keflavik	1369	542	5113	104
Improved glass Keflavik	1364	542	5095	105.6
Reference glass Eyrarbakki	1256	554	5273	105.3
Improved glass Eyrarbakki	1259	553	5248	107
Reference glass Akureyri	1132	549	5119	103.7
Improved glass Akureyri	1133	547	5100	105

Finally, the small amount of sunlight under the improved glass translates into an increase in final potential yield(+ 1.5%), which is less than the 5% values that could be expected in a greenhouse without artificial lighting. The artificial lighting system is compensating the lower PAR transmission of the reference glass with a higher number of hours of functioning.

The previous result indicate the small differences in energy requirements for heating, artificial lighting and yield between the three studied locations; especially equal are the values for Keflavik and Eyrarbakki. This justifies to focus only in one of these two locations from now on, which will be Keflavik, for which a TMY is available, which ensures to capture better the climate inter-year variability.

4.2.2 Energy use for heating: screens and dehumidification

We have calculated the average number of snow days for Keflavik and Akureyri and the average snow precipitation per day of that month, using the data from website (Table 20, Table 21,Table 22 and Table 23) (https://www.worldweatheronline.com/lang/es/keflavik-weather-averages/gullbringusysla/is.aspx). (https://www.worldweatheronline.com/akureyri-weather-history/eyjafjardarsysla/is.aspx)

Table 21

Number of snow days during the months with snow in Keflavik (last 10 years).

	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	Average
October	2	0	0	0	0	2	0	0	0	1	0.5
November	5	1	4	4	6	0	4	2	6	3	3.5
December	2	6	8	3	5	8	7	4	4	6	5.3
January	2	6	8	3	4	6	4	7	7	14	6.1
February	3	4	3	1	2	3	8	8	5	6	4.3
March	5	10	9	6	7	7	3	7	3	16	7.3
April	3	7	4	5	4	5	0	8	1	1	3.8
May	0	0	2	0	0	1	0	0	1	0	0.4

Table 22

Number of snow days during the months with snow in Akureyri (last 10 years).

	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	Average
September	0	3	2	1	0	0	0	0	3	2	1.2
October	11	9	10	12	14	5	3	1	13	6	8.4
November	18	10	18	14	3	17	15	22	8	10	13.5
December	15	27	16	22	23	20	12	21	13	27	19.6
January	8	19	22	14	18	21	15	21	20	21	17.9
February	14	17	22	9	20	14	18	12	16	20	16.2
March	20	24	17	21	22	22	13	20	18	25	20.2
April	20	17	17	19	12	15	11	18	14	5	14.8
May	5	5	11	8	4	12	9	1	6	8	6.9
June	0	1	1	0	0	4	0	0	2	4	1.2

Table 23

Snow precipitation (cm) and energy required to melt this snow (MJ m^{-2}) during the months with snow in Keflavik (last 10 years).

	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	Energy to melt average monthly snowfall (MJ m^{-2})
October	1.4	0	0	0	0	0.6	0	0	0	0	0.2
November	3.4	0	3.4	0.9	5.9	0	3.5	0.8	5.1	1.4	2.9
December	0.1	5.4	8.9	2.9	4.6	7.6	4.3	5.2	1.9	3.1	5.2
January	0.2	2.4	12.4	3.4	1.4	2.5	1.9	3.8	2.4	21.8	6.2
February	1.3	5.5	3.2	0.5	0.6	5.6	3.6	7.3	2	5.2	4.2
March	3.1	15.7	3.7	2	6.4	5.6	2.4	3.9	0.2	9.9	6.3
April	0.8	7.9	0.3	0.7	5.4	3.4	0	5.4	2.7	2.3	3.5
May	0	0	0.1	0	0	1.5	0	0	0.2	0	0.2

Table 24

Snow precipitation (cm) and energy required to melt this snow (MJ m^{-2}) during the months with snow in Akureyri (last 10 years).

	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	Energy to melt average monthly snowfall (MJ m^{-2})
September	0	3	10.6	1.3	0	0	0	0	4.3	0.4	2.4
October	20.7	13	9.8	18.8	21.7	9.4	2.2	0.2	30.6	44.4	20.4
November	39.9	23.9	40.6	30	3.1	48	15	28.5	15.2	5.1	29.7
December	12.6	31.5	35	31.8	43.1	37.5	33.6	38.4	48.2	224	64
January	2.4	39.2	43	20.9	32.1	32.8	18.4	33.7	26.8	75.1	38.7
February	23	14.5	37.6	11.9	36.5	25.7	34.3	26.3	26.1	56.5	34.8
March	16.5	37.1	26.6	18.6	33	41.6	27.1	26.7	27.7	79.1	39.9
April	18.3	11.1	15.6	28.8	12.8	24.8	7.3	34.8	16.8	11.4	21.7
May	3.5	3.5	10.2	11.1	1.8	9.5	16.1	5.4	5.4	10.8	9.2
June	0	2.3	0.4	0	0	2.3	0	0	0.9	1.5	0.83

It takes 0.33 MJ to melt 1 kg of snow to liquid form. Snow can be wet or dry. Wet snow is heavier than dry snow. Wet snow is more likely to fall in coastal locations. Since Keflavik and Akureyri are near the cost, we will assume that all the snow falling in these locations is wet snow. One cm of wet snow over a square meter weighs 3.34 kg, multiplied by 0.33 MJ/kg = 1.1 MJ needed to melt it. Since the ratio of roof area to ground area is 1.085, the final values of energy required per square meter of greenhouse must be increased by this factor

A simulation has been done in which no blackout screen was used, in order to estimate the energy required for heating for the days that it must remain open due to snow fall, for both Keflavik and Akureyri (Table 24 and Table 25).

Table 25

Calculation of the extra energy required due to snow fall for Keflavik.

	Average daily energy requirement no screen (MJ/m^2 day)	Average daily energy requirement screen (MJ/m^2 day)	Extra energy to be added per snow day due to the impossibility to use the screen (MJ/m^2)	Extra energy to be added each month due to impossibility to use the screen (MJ/m^2)	Total energy required due to snowfall (MJ/m^2)
October	5.4	4.1	1.3	0.6	0.8
November	5.3	3.9	1.5	5.1	8
December	7.2	5.1	2.1	11.0	16.2
January	7.1	5.3	1.8	11.1	17.3
February	7.0	5.5	1.5	6.5	10.7
March	5.6	4.4	1.1	8.4	14.7
April	5.6	4.8	0.8	3.1	6.6
May	4.9	4.2	0.7	0.3	0.5
Total	-	-	-	-	74.8

Table 26

Calculation of the extra energy required due to snow fall for Akureyri.

	Average daily energy requirement no screen (MJ/m^2 day)	Average daily energy requirement screen (MJ/m^2 day)	Extra energy to be added per snow day due to the impossibility to use the screen (MJ/m^2)	Extra energy to be added each month due to impossibility to use the screen (MJ/m^2)	Total extra energy required due to snowfall (MJ/m^2)
Sept.	2.0	1.5	0.5	0.6	3
October	4.6	3.5	1.1	9.3	29.7
Nov.	6.1	4.5	1.6	22.0	51.7
Dec.	4.2	2.8	1.4	27.6	91.6
January	5.6	4.2	1.4	24.4	63.1
February	5.4	4.3	1.0	16.8	51.6
March	5.1	4.3	0.8	16.5	56.4
April	3.7	3.2	0.4	6.4	28.1
May	3.2	2.8	0.4	2.9	12.1
June	1.8	1.6	0.2	0.2	1.03
Total	-	-	-	-	388.3

These calculations show, that on average, it takes an extra of approximately 75 MJ/m^2 of energy to deal with the snow in a greenhouse in Keflavik (Iceland) on a whole growing cycle, which is approximately 5% of the energy used by the heating system to maintain the temperature set point.

However, in Akureyri, the average amount of energy required to melt the snow is larger, 23% of the amount of energy required to maintain the temperature set point.

The knowledge of the heating power that is required to deal with the snow must be calculated from data of maximum snowfall rate per hour. A typical peak value for heavy snowfall is around 500 W/m^2, much larger than the 200 W/m^2 required to maintain the heating set points.

The use of a screens involves an increase in the insulation of the greenhouse. The moisture generated from crops transpiration is transported at a lower rate through the screen, which is a barrier for sensible and latent heat transfer. Therefore, less moisture can be both condensed on the roof and/or ventilated away. The consequence is that humidity may increases in the lower compartment to undesired high levels. When artificial light is used, crop transpiration is even larger, and therefore, humidity needs to be managed. A grower can do the de-humification in several ways. Opening screen gaps and ventilating more is the best option, but it is done at the expense of more energy use. We have simulated this option for Keflavik and Akureyri, and with this option, simulations indicate the number of hours that the greenhouse relative humidity values are above the established set point of 85% is 3379 and 3826, respectively for Keflavik and Akureyri, but the number of hours with humidity above 88% decreases drastically to only 828 hours and 979, respectively for Keflavik and Akureyri; finally, only 236 hours and 262 hours above 90% relative humidity, respectively for Keflavik and Akureyri. Considering all this, we think the use of a dehumidification system is not a priority, especially considering the abundance of "cheap" geothermal energy in Iceland. However, a relatively cheap solution which is been implemented in a large number of Dutch farms is the use of vertical farms that can enhance the sensible and latent heat transport between the two compartments separated by the screen. In this way, dry cold air is transported from top to lower compartment and warmer and more humid air is transported to the top compartment at a much higher rate than under natural convection. This moisture then condenses in the cold roof, dehumidifying the greenhouse. The simulated vertical fan capacity was 20 m^3/m^2 h. The simulations indicate no gain by using the screen fans, as the number of hours in which relative humidity in the greenhouse is above 90% decreases, for instance, for Akureyri from 262 to 248. However, different measurement in commercial fans indicate the use of this fans can lead to more homogenous climate in the greenhouse (something we cannot capture with our stirred tank model), so we still believe it is an interesting investment.

4.2.3 The artificial lighting system

Simulations have been made with two different types of lamps: HPS and LED lamps. For each type of lamp, 3 different maximum PAR intensities have been simulated: 220 $\mu mol\ m^{-2}\ s^{-1}$, 250 $\mu mol\ m^{-2}\ s^{-1}$ and 280 $\mu mol\ m^{-2}\ s^{-1}$.

The use of one type of lamp or the other, has mostly an effect on the use of resources, since the higher electric efficiency of LED's leads to a saving on electricity in relation to HPS (Table 16), although the energy for heating grows, as the LED's are providing less sensible heat per electrical Watt. This also means that the crop transpires less under the LED lamps and therefore, the total water use is lower. The CO_2 is almost unaffected, with slighter use under the HPS lamps, caused by the higher losses of CO_2 through the vents, due to slightly higher ventilation requirements when HPS lamps are used (to evacuate the excess humidity caused by the slightly larger transpiration). The use of higher intensities increases the use of electricity, decreases the use of energy required from the heating system, increase the use of CO_2 and water but also increase the yield when intensity is increased from 220 to 250, but not when it is increased to 280 (due to larger ventilation requirements originated by excess sensible heat). The economic analysis must determine whether higher PAR intensities are interesting or not.

Table 27

Summary of yearly sum of most important greenhouse resources that can quantified by the simulation model and potential tomato yield, for different combinations of lamps and maximum PAR intensities.

	Energy used for heating(MJ m^{-2})*	Electricity used for artificial lighting	Hours lamps are on (h)	Amount of CO_2 used (kg/m^2)	Water use (L/m^2)	Tomato yield (kg/m^2)
HPS-220	1442	542	5095	32.2	1028	105.6
LED-220	1906	333	5109	30.5	951	105.5
HPS-250	1358	615	5076	34.6	1088	110.7
LED-250	1840	378	5094	32.2	983	109.2
HPS-280	1257	678	4959	35.8	1115	109.5
LED-280	1787	419	5010	33.5	1009	108.9

* This number already includes the extra energy required on an average year to deal with the snow in Keflavik

4.2.4 Analysis of the microclimate and resource use and solutions to climate problems

In this section we analyse how close we are to the established set points for the three main microclimate parameters affecting productivity (temperature, PAR and CO_2 concentration), again, and in order to minimise the work, only for Keflavik, assuming that these results are representative for Akureyri as well. Since the set points have been established trying to provide an optimum microclimate for the crop, the closer we will be to the maximize the yield. This analysis is done using the greenhouse set up that we consider from now on as the standard or reference configuration:

- Greenhouse cover: improved glass with an AR coating.
- Blackout screen (open on snow days).
- Vertical screen fans.
- Artificial light with HPS lamps (maximum intensity of 220 μmol $m^{-2}s^{-1}$).

4.2.4.1 Temperature

If greenhouse air temperature values are within the limits established by the heating and the ventilation set points, the crop is in the region where net photosynthesis can occur with maximum efficiency. For this analysis we will focus on the 7 different periods in which these set points were modified (Table 7). Temperature is in every period within the defined boundaries, except for small periods during the 24 hours, deviations in any case never higher than 1 °C. The exception is Period 1, when crop is small and does not intercept much light, and greenhouse temperature becomes only marginally higher (less than 1 °C) than the ventilation set point. The limited use of the vents during most of the year is proved by the fact that temperature is most of the day nearer to the heating set point than to the ventilation set point. This scenario is almost ideal for the crop to develop in optimum conditions, provided that there is enough PAR radiation (Figure 29, Figure 30, Figure 31, Figure 32, Figure 33, Figure 34 and Figure 35).

Period 1 (07-9 to 01-10)

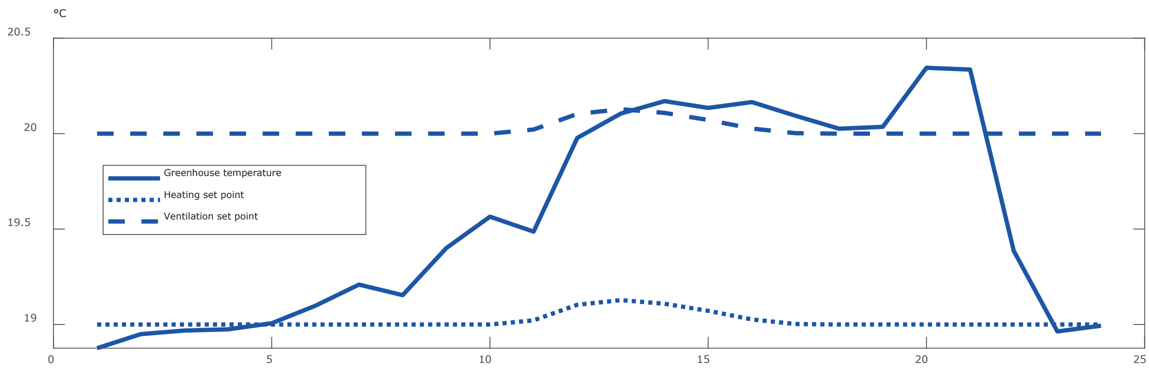

Figure 29 *Daily cyclic mean of greenhouse air temperature (°C) and heating and ventilation set points during period 1.*

Period 2 (02-10 to 01-11)

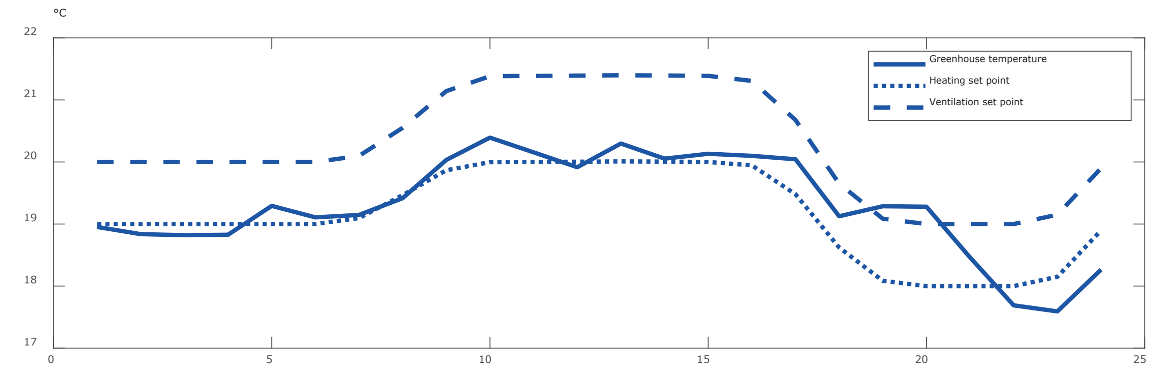

Figure 30 *Daily cyclic mean of greenhouse air temperature (°C) and heating and ventilation set points during period 2.*

Period 3 (02-11 to 01-03)

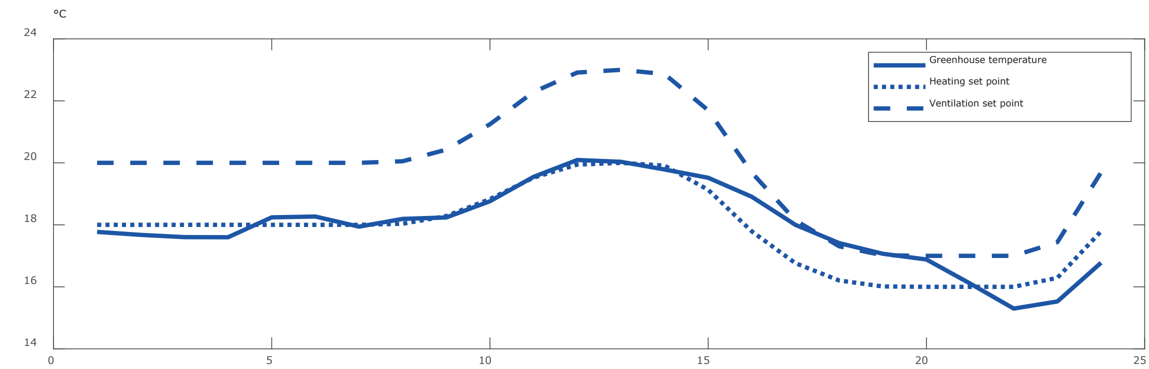

Figure 31 *Daily cyclic mean of greenhouse air temperature (°C) and heating and ventilation set points during period 3.*

Period 4 (02-03 to 01-04)

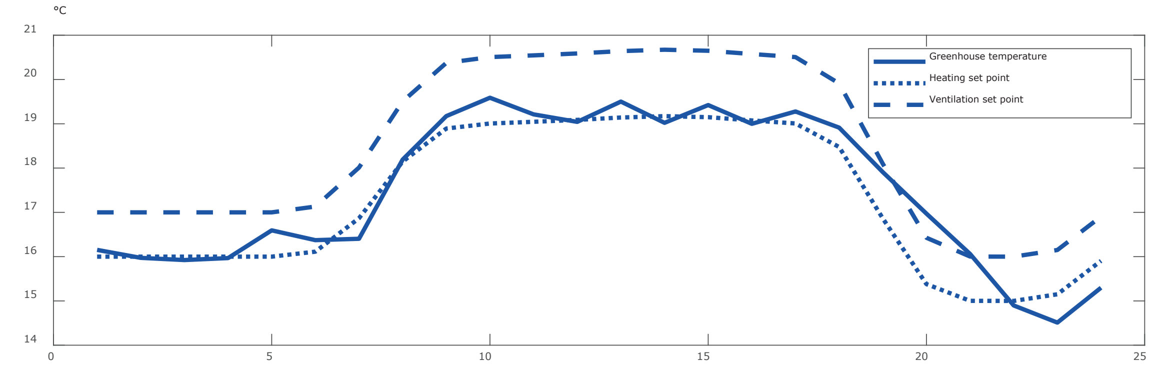

Figure 32 *Daily cyclic mean of greenhouse air temperature (°C) and heating and ventilation set points during period 4.*

Period 5 (02-04 to 01-06)

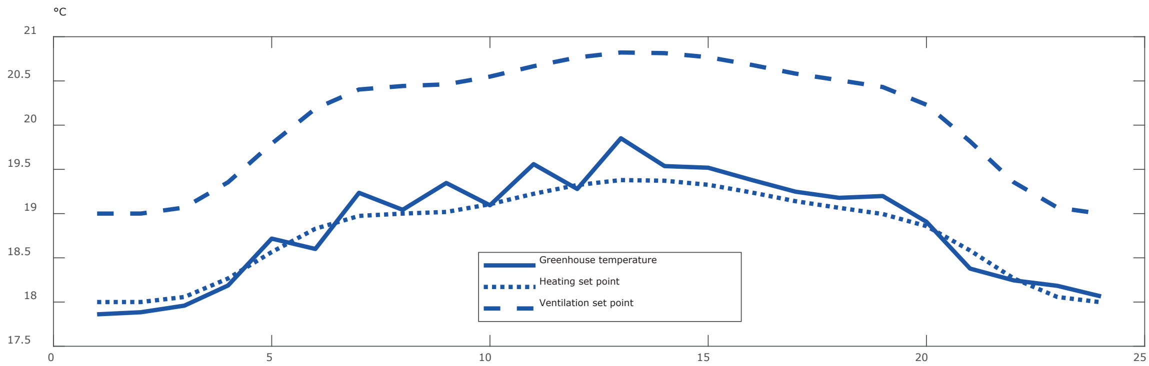

Figure 33 *Daily cyclic mean of greenhouse air temperature (°C) and heating and ventilation set points during period 5.*

Period 6 (02-06 to 15-08)

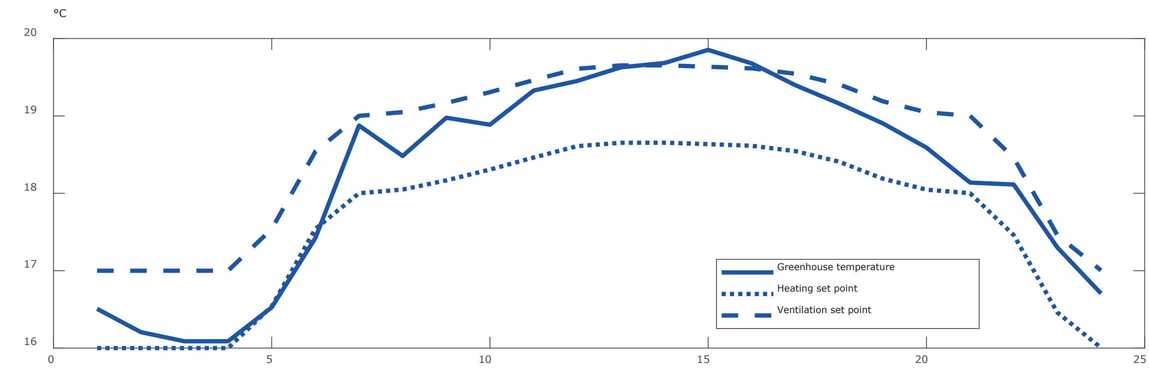

Figure 34 *Daily cyclic mean of greenhouse air temperature (°C) and heating and ventilation set points during period 6.*

Period 7 (16-08 to end growing cycle)

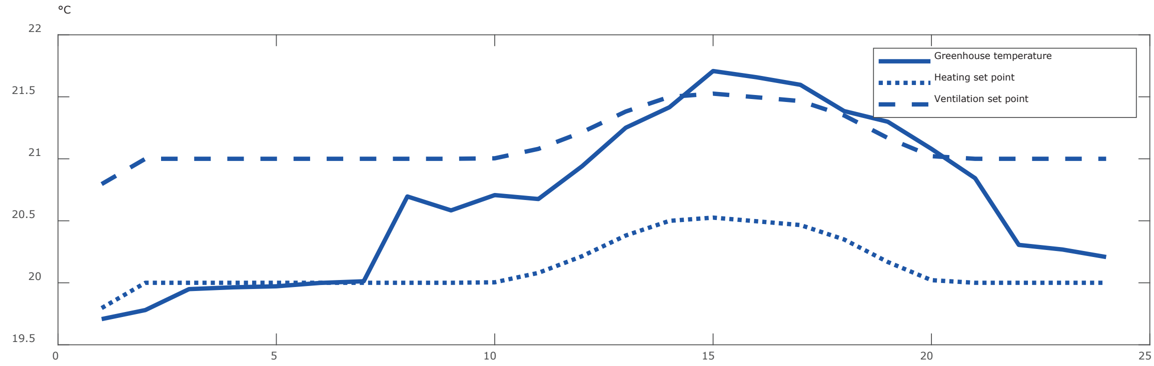

Figure 35 *Daily cyclic mean of greenhouse air temperature (°C) and heating and ventilation set points during period 7.*

4.2.4.2 PAR

Between October and April, there is hardly any contribution of the sun to the daily PAR sum available for the crop, and the PAR comes almost exclusively from the artificial lighting system. Between April and September there is a larger number of days when the sun contributes significantly to daily PAR sum. The amount intercepted by the crop grows until full crop size is reached, and during the winter, intercepted light is around 60% and only reaches values close to 80% during the longer and clearer days of the spring and summer period. The artificial light ensures, therefore that on each day, the crop receives at least he minimum amount of PAR per day required to produce a new flower truss, every week (13 mol/m²) (Figure 36)

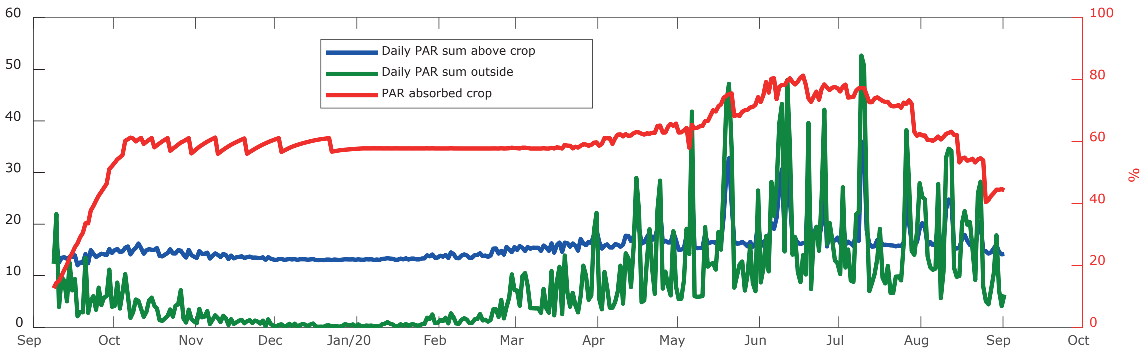

Figure 36 *Daily PAR sum (mol/m² day) and average daily absorbed PAR radiation (%) during the growing cycle.*

4.2.4.3 Carbon dioxide (CO_2)

For the analysis of the carbon dioxide concentration we can divide the crop cycle in two periods, one from transplant to April, with lower temperatures and less ventilation requirements, and from April to end of the cycle, with more solar radiation, higher temperatures and more ventilation requirements (Figure 37 and Figure 38).

During the cold period, the set point can be faithfully maintained during the 16 hours of illumination, indicating very small ventilation exchange through the vents, as expected, whereas during the second period, the slightly larger ventilation requirements involve a certain loss of CO_2 through the vents.

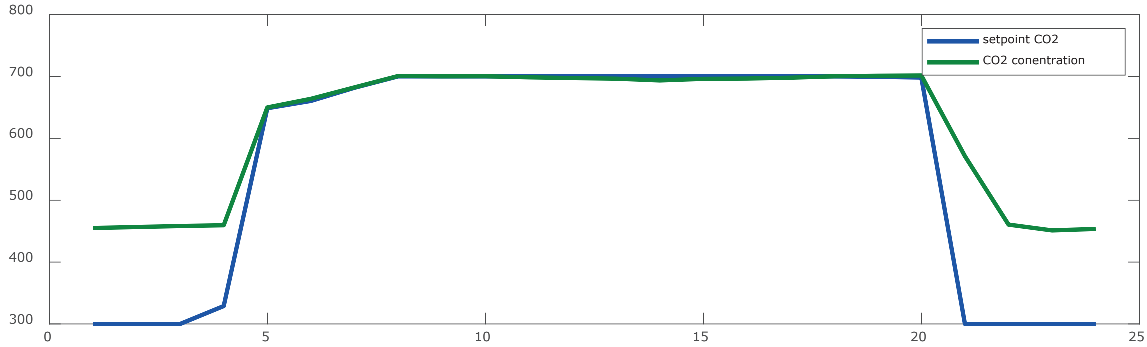

Figure 37 *Daily cyclic mean of carbon dioxide concentration (ppm) in the greenhouse and the established set point (ppm) in the dark/cold period of the growing cycle.*

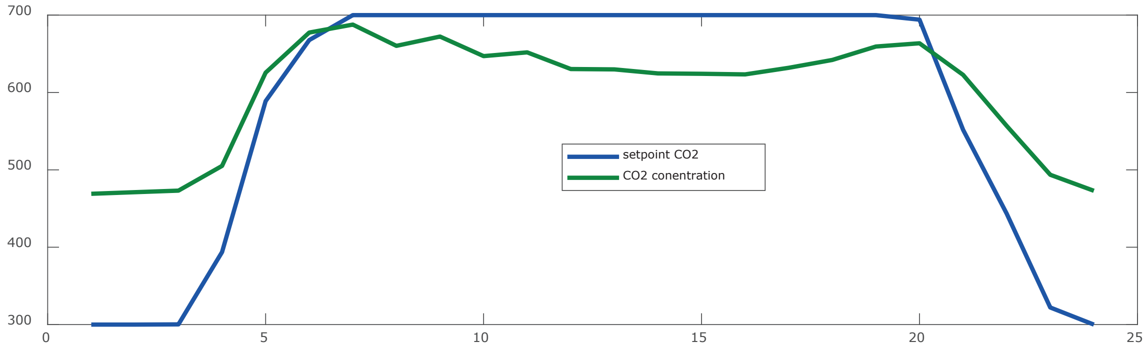

Figure 38 *Daily cyclic mean of carbon dioxide concentration (ppm) in the greenhouse and the established set point (ppm) in the sunnier/warmer period of the growing cycle.*

4.2.5 Conclusion for tomato design

Both temperature and CO_2 can be maintained within the optimum established range of values. PAR comes part of the cycle mostly from the lamps and during other part of the cycle is supplemented by the sun radiation. Maintaining optimum values during the dark part of the cycle would involve installing a very large capacity of the lamps, which would also mean an excess of sensible heat in the greenhouse, so more ventilation required and less carbon dioxide. Therefore, increasing the artificial light intensity only leads to a yield increase up to a certain threshold, above which, the excess of sensible heat in the greenhouse needs to be ventilated away, decreasing CO_2 concentration, and therefore, penalizing dry matter production.

Table 27 summarizes the predicted sum of main resources for both studied locations (Keflavik and Akureyri) for the reference scenario, that is, the one with HPS lamps with an intensity of 220 micromols/m^2 s

Table 28

Summary of main resource uses and predicted tomato yield for Keflavik and Akureyri.

	Energy used for heating and snow melting (MJ m^{-2})*	Electricity used for artificial lighting	Hours lamps are on (h)	Amount of CO_2 used (kg/m^2)	Water use (L/m^2)	Tomato yield (kg/ m^2)
Keflavik-reference scenario	1442	542	5095	32.2	1028	105.6
Akureyri-reference scenario	1522	547	5100	28.8	1003	105

* This number already includes the extra energy required on an average year to deal with the snow in Keflavik and Akureyri

4.3 Design for lettuce production

Lettuce is a fast growing crop. With the right amount of light and optimum temperature (24 °C), it is possible to grow a marketable size lettuce (330 g) in around 28 days.

The design for tomato does not have to change drastically for lettuce production. The accepted recommended daily light PAR integral for lettuce is 13 mol/m^2 day. Since the contribution of the sun in winter can be considered negligible, then the artificial system has be able to provide the 13 mol /m^2 day. If we assume 16 hours of light and 8 hours of darkness, a light intensity of 230 micromol/m^2 s, would be required. Both a supra-optimal and infra-optimal light intensity of 200 micromol/m^2 s and 260 micromol/m^2 s have been simulated as well, to analyse their effect on potential yield and use of resources. For lettuce yield prediciton, the model proposed by van Henten *et al.* (1994) was used.

In relation to temperature, different studies indicate that the economic gain from moving from a constant temperature set point to a more complex strategy providing higher set points during early stages of development to lower values when crop is in the latter stages.

Therefore, we are going to simulate the crop with the following combinations of temperature and artificial light intensities (Table 28).

Table 29

Combinations of temperature and lamp PAR intensities simulated for lettuce production in Iceland.

Day/night set point (°C)	Light intensity 200 micromol/m^2 s	Light intensity 230 micromol/m^2 s	Light intensity 260 micromol/m^2 s
18/15	X	x	x
15/12	x	x	x
12/9	x	x	x

Simulations have been done both with LED and HPS lamps, and again, only for the Keflavik location, given the minimum differences in resource use and light availability found between this location and Akureyri, except for the amount of energy required to deal with the snow (Table 29 and Table 30), which must be added for each location to the energy required for heating .

Table shows a summary of the most relevant consumptions (energy for heating, electricity for the lamps, CO_2 and water) and the total yield in heads per square meter (heads of 330 g).

Table 30

Summary of use of main resources and predicted potential yield for different combinations of PAR light intensities of the HPS lamps and different heating/ventilation set points.

	Energy used for heating* (MJ m^{-2})	Electricity used for artificial lighting (KWh/m^2)	Hours lamps are on (h)	Amount of CO_2 used (kg/m^2)	Water use (L/m^2)	Lettuce yield (heads/m^2)
HPS-200/12-9	485	520	5269	39.1	723	155
HPS-200/15-12	944	520	5269	36.6	817	159
HPS-200/18-15	1480	520	5269	33.9	930	159
HPS-230/12-9	441	574	5031	39.9	754	161
HPS-230/15-12	875	574	5031	37.4	846	165
HPS-230/18-15	1395	574	5031	34.5	958	165
HPS-260/12-9	419	600	4631	39	770	163
HPS-260/15-12	846	601	4631	37.4	860	166
HPS-260/18-15	1360	601	4631	34.6	972	166

* This number already includes the extra energy required on an average year to deal with the snow in Keflavik

Table 31

Summary of use of main resources and predicted potential yield for different combinations of PAR light intensities of the LED lamps and different heating/ventilation set points.

	Energy used for heating* (MJ m^{-2})	Electricity used for artificial lighting (KWh/m^2)	Hours lamps are on (h)	Amount of CO_2 used (kg/m^2)	Water use (L/m^2)	Lettuce yield (heads/m^2)
LED-200/12-9	765	321	5305	37.6	631	152
LED-200/15-12	1336	321	5305	35.7	739	159
LED-200/18-15	1920	321	5305	32.8	858	160
LED-230/12-9	717	355	5074	38	648	159
LED-230/15-12	1276	355	5074	36	755	165
LED-230/18-15	1854	355	5074	33.4	874	166
LED-260/12-9	694	372	4669	37.7	656	160
LED-260/15-12	1248	372	4669	36.1	762	166
LED-260/18-15	1827	372	4669	33.5	880	167

* This number already includes the extra energy required on an average year to deal with the snow in Keflavik

For both LED and HPS lamps, the model predicts a substantial increase in yield when light intensity increases from 200 to 230 micromol/m^2 s, but a much smaller increase when light intensity increases to 260 micromol/ m^2s, regardless of the heating temperature. In the same way, the increase in yield obtained by increasing the day/night set points from 12/9 to 15/12 is much larger than the increase obtained when increasing to 18/15. The increase of PAR intensity involves a substantial increase in electricity use and a decrease in the amount of energy that the heating system must supply, as a largest part of the energy is provided by the lamps. The increase in the set points has a very large effect on the amount of energy required for heating which becomes almost 3 times larger when a heating set point of 18/15 is used instead of a 12/9 set point. The higher the light intensity, the lower the number of hours that the lamps are used, because the DLI has been reached and then, lamps are turned off. The higher the temperature set points, the lower is the CO_2 consumed, because there is less ventilation and therefore, less leakage to the outside.
Finally, we observe slightly lower yield for LED than with the HPS lamps, when the set points are lower, but almost the same values at the two higher set point scenarios.

Only the economic analysis can tell which is the best strategy.

5 Indoor factory design

In the last 5 years there has been an increasing interest in indoor cultivation, aka plant factory concept. IN this type of cultivation, the plants are grown in complete insulation with the outside environment, including the absence of solar radiation, which is fully replaced by the use of artificial light. Why leave out solar radiation, which is the main free resource in plant cultivation? There are several reasons:

1. It gives the possibility of designing and controlling optimum growing conditions, which remain unaltered regardless of the outside weather conditions.
2. In this way it is possible to schedule production with most precision and it is relatively easy to advance or delay the harvests a certain amount of time by specific modifications in the climate and fertigation set points, crop management, etc.
3. Possibility for some crops of low height (i.e. Leafy crops, strawberry, etc.) to grow in multiple layers, increasing productivity in the use of the land.
4. Automation and robotization of crops tasks becomes easier and more efficient with a more synchronized crop.
5. Possibility to generate a completely sterile environment where virtually not plant protection interventions are needed.
6. High resource use efficiency.

On the other hand, indoor growing systems are very energy intensive, because all the light must be provided artificially and because a large amount of cooling/dehumidification is needed (as a rule of thumb, 1.5 times the amount of energy used for lighting is needed for cooling/dehumidification). In addition, some heating is needed for the dark hours in which the lights are turned off (most crops benefit from some hours of darkness to maintain their circadian rhythms). Finally, the initial investment in these type of systems is very high, but not when compared with a high tech greenhouse which also needs to rely on artificial lighting.

Therefore, the question is, in location like Iceland, where the contribution of solar radiation to productivity is so small on a year round basis, does it make sense to simply grow indoor and gain all the advantages that this system has and which we have already described? Or is it still worth to grow in a greenhouse and use the free solar energy? This is a complex question that depends on which is your final market and which only a detailed economic analysis can answer this questions. Even though, for some crops it might be true that growing indoors is indeed a more profitable option and in some others not.

In the present work, we have used the greenhouse climate and crop growth simulation models Kaspro/Intkam, to mimic an indoor growing system, and simulate the microclimate, use of resources and productivity for both a tomato and a lettuce crop, representing both a "warm" and a "cold" crop, respectively.

5.1 Detailed set-up of the indoor growing simulations

To mimic an indoor growing, we have created a greenhouse cover file which both opaque to solar radiation and extremely insulating, and for that we have chosen to mimic a sandwich panel.

In addition, we have highly decreased the leakage, making it 10 times lower than that of high tech greenhouse. Since the indoor growing system as no natural ventilation air exchange, we have minimized the size of the vents to make airflow exchange by ventilation negligible. We have activated a cooling/dehumidification system with a maximum cooling power of 400 W/m^2. We have simulated an artificial lighting system based on LED's with an efficienty of 2.9 micromols per Joule, with a maximum intensity of 550 micromols/m^{2}s. Therefore, the artificial lights have a power of 189.6 W/m^2. The artificial lights are on during 18 hours per day.

5.2 Results for tomato

A first check was necessary to make sure that the settings are mimicking an indoor growing facility. For that, a triple check was made:

1. Make sure the heat losses through the roof are minimum (Figure 39). This holds, as the heat losses are minimum, never reaching values of more than 7 W/m^2 in the coldest moments.
2. Make sure that the leakage is very small. For this we check the yearly sum of CO_2 losses, which is only 0.87 kg/m^2 year, a very small amount of CO_2 loss.
3. Make sure that the ventilation exchange with the outside is extremely low (Figure 40), which also holds because the average hourly air exchange is 28 times smaller than the air exchange in the simulated greenhouse in this same location (Keflavik).

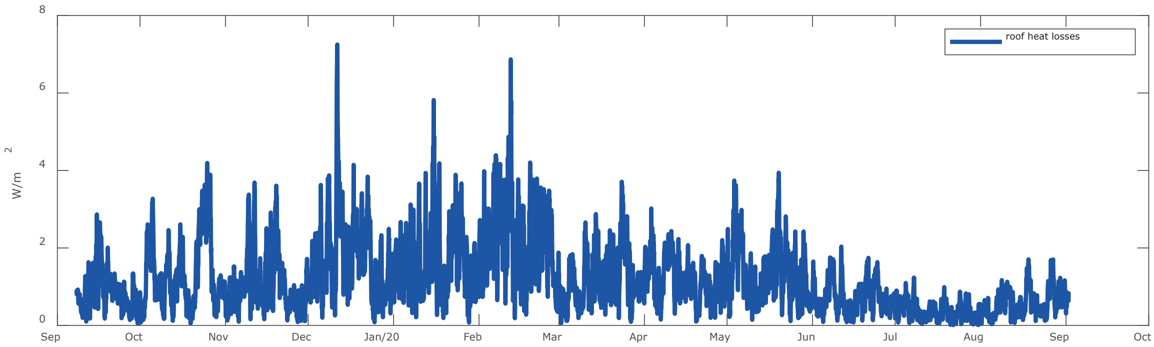

Figure 39 *Evolution of hourly values of heat loss through the building cover (W/m²).*

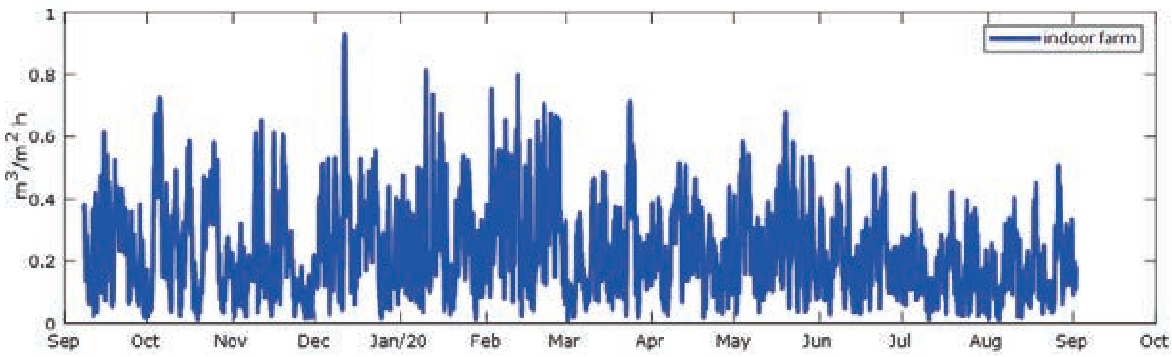

Figure 40 *Evolution of hourly values of ventilation exchange (m³/m² h).*

In an indoor growing facility, the air temperature, relative humidity and CO_2 concentration must remain very close to the established set points, which has been verified for this situation. In all cases we observe that the values are maintained very close to the set points, which should ensure a very positive effect on dry matter production.

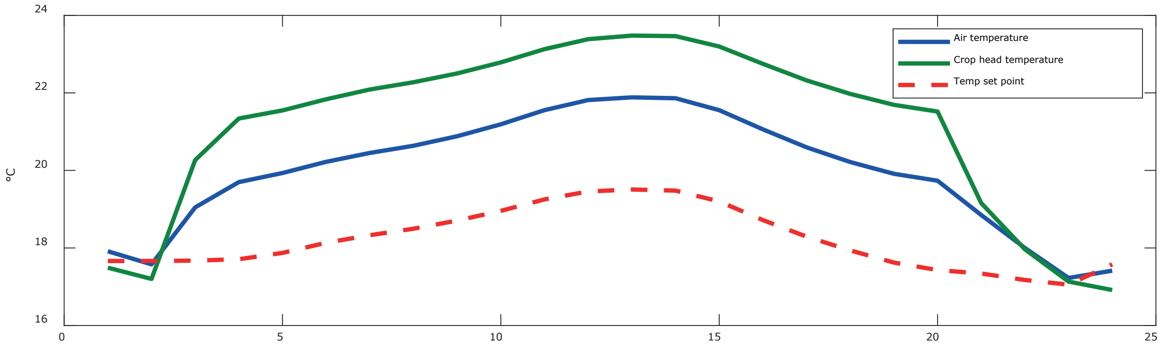

***Figure 41** Daily cyclic mean of air and crop head temperature (°C) and heating set point for the whole growing cycle.*

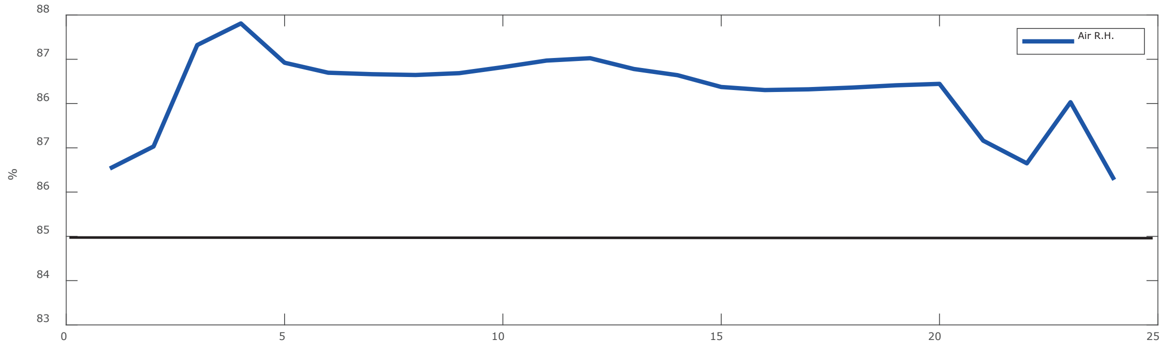

***Figure 42** Daily cyclic mean of air R.H. (°C) and R.H. set point (black line) for the whole growing cycle.*

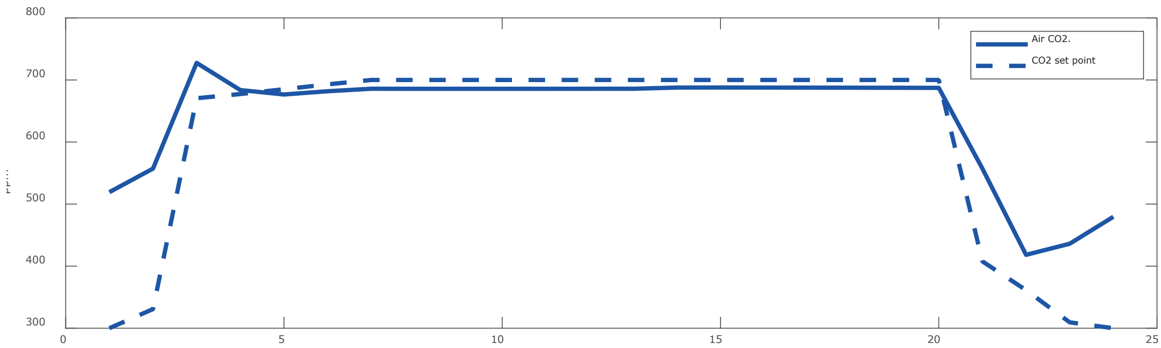

***Figure 43** Daily cyclic mean of carbon dioxide concentration in the air(ppm) and the set point for the whole growing cycle.*

The daily sum of mol/m^2 day shows that all radiation is coming from the lamps, and the result is that each day the plants are receiving 35.6 mol/m^2 day, a value that can be considered as an optimum amount of light for a tomato crop (Figure 44).

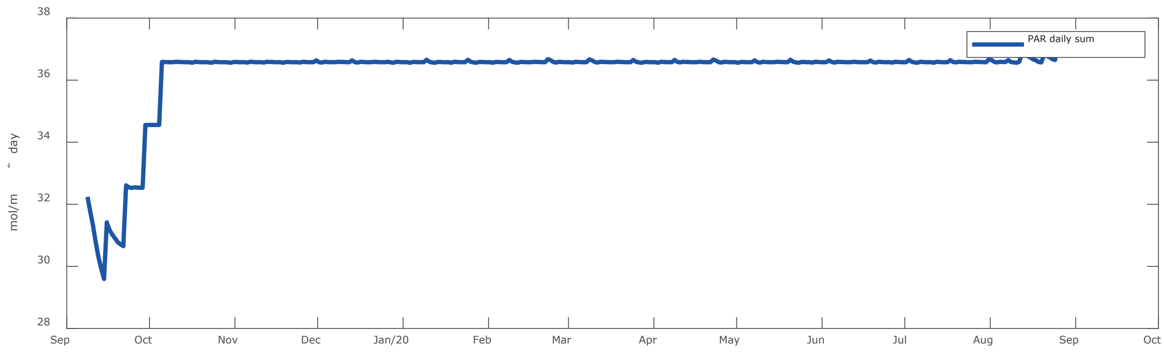

Figure 44 *Evolution of the daily PAR sum (mol/m² day) provided by the LED lamps for the whole growing cycle.*

We must also analyse the cooling power used to maintain the temperature and for that we can plot a duration curve load, which can be used to interpolate the amount of hours that the cooling system is running above a certain cooling power (Figure 45). Results indicate that the peak cooling energy required is 200 W/m², thus, this must be the design value for the cooler capacity.

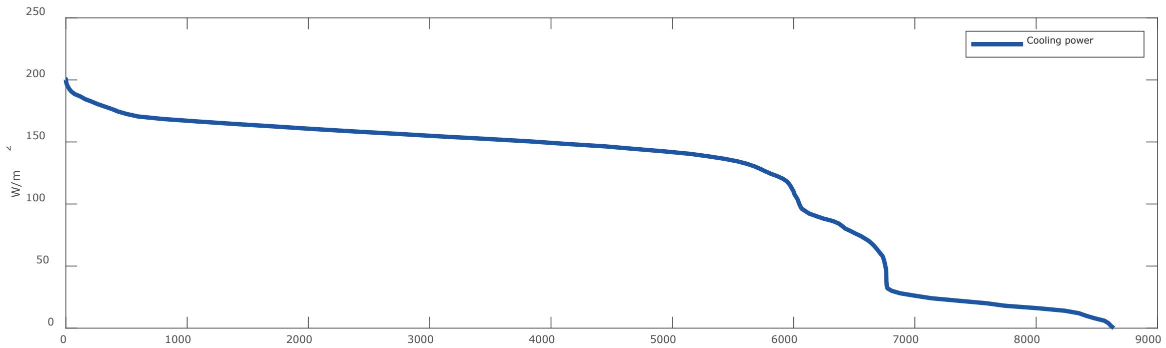

Figure 45 *Duration load curve of cooling power (W/m²) in the simulation of a whole tomato growing cycle in an indoor growing environment.*

Finally, during the hours that the lamps are off (6 hours per day) the latent heat recovered from the cooling system can be stored and used to maintain the desired temperatures. The amount of energy which is used for this dark period is relatively low and never peaks above 60 W/m².

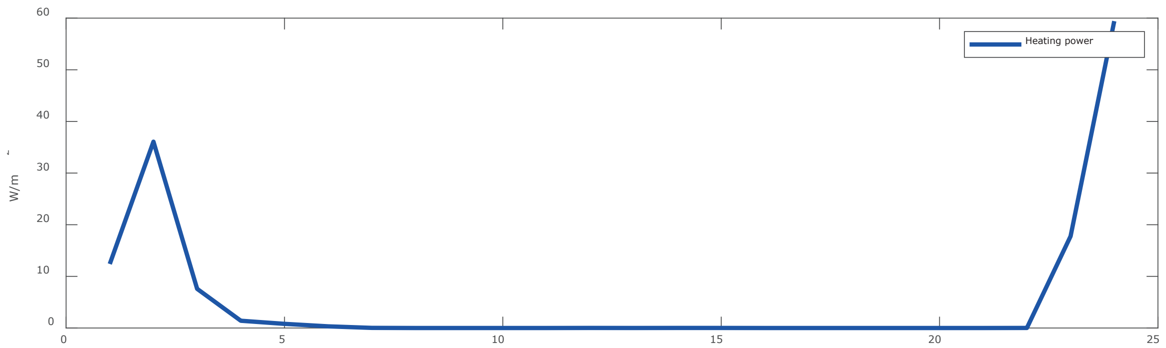

Figure 46 *Daily cyclic mean of waste heat(W/m²) provided for heating during dark hours.*

Table 31 summarizes the final use of main resources and the predicted yield by the model for three different light intensities (350 micromol/m²s, 450 micromol/m²s and 550 micromol/m²s)

Table 32

Summary of use of main resources and predicted tomato yield in an indoor growing farm in Iceland with different light intensities.

	Electricity used for cooling (KWh/m²)	Energy used for heating (KWh/m²)	Electricity used for artificial lighting (KWh/m²)	Hours lamps are on (h)	Amount of CO_2 used (kg/m²)	Water use (L/m²)	Tomato yield (heads/m²)
Tomato 350 micromol/m²s	201	54.9	777.4	6771	18.2	944.5	129.1
Tomato 450 micromol/m²s	268.1	51	1000	6771	21.9	1170	143.3
Tomato 550 micromol/m²s	343	49	1221	6771	25.5	1394	151.1

5.3 Results for lettuce

For lettuce, we make our simulations assuming only one level, but under normal circumstances, you should grow at more levels to make better use of space. We have simulated a building which has 6 m height, so we can assume that we will have at least 2 m separation with the roof and that the first layer is 1 m above the ground. That leaves 3 m for cultivation. Assuming that each layer requires 60 cm, we could have 5 levels. Table 32 summarizes the values obtained from the simulations of final use of resources per ground floor square meter and predicted yield in heads per ground floor square meter, multiplied by 5 to obtain the final value. The yield is expressed in heads of 330 g each.

Table 33

Summary of use of main resources and predicted lettuce yield per ground floor unit area in an indoor growing farm with 5 levels in Iceland with different light intensities.

	Electricity used for cooling (KWh/m²)	Energy used for heating (KWh/m²)	Electricity used for artificial lighting (KWh/m²)	Hours lamps are on (h)	Amount of CO_2 used (kg/m²)	Water use (L/m²)	Lettuce yield (heads/m²)
Lettuce 230 micromol/m²s	292	545	2581	6840	17.3	2812	804
Lettuce 330 micromol/m²s	462	249	3704	6840	21.7	3743	992
Lettuce 430 micromol/m²s	766.5	192	4827	6840	26	4935	1163

6 Yield and electricity consumption prediction for other crops under plant factory and greenhouse conditions

In the list of 8 crops selected for this study, there are other 6 crops (potato, rice, sweet pepper, banana, avocado and raspberry) for which we simply do not have available specific crop growth models to estimate their yield. A simplified way of estimating the potential yield that could be achieved in the optimum growing conditions that can be provided in a plant factory is to find in the literature light use efficiency values (g dry matter per mol of PAR) from these crops when grown in the regions that have an optimum climate for them, from there, and knowing the optimum PAR sum that we can provide in the plant factory, we can estimate the total plant dry matter that we can produce. Multiplying this number by the harvest index (percentage of harvestable biomass of the crop) and dividing by the average dry matter content of the harvestable fraction, we have a very good estimation of the fresh weight that can be harvested on a yearly basis.

6.1 Potato in plant factory

The highest tuber yields are obtained in areas with temperate climates in North-western Europe and the North-West of the United States. The highest tuber yields have been reported at temperatures between 18 and 21°C, which means, that potatoes can be growing in similar conditions as tomato in an indoor farming facility. Potato has a harvest index of 0.8, which is high. However, this same feature may lead to lower yields since it may reduce the amount of foliage formed and hence the amount of radiation intercepted. And since total crop dry matter production results from the amount of intercepted radiation and its efficiency for dry matter production, tuber yields will be lower as well. To obtain a maximum tuber yield, there must be optimal dry matter allocation to the leaves (assuring light interception and thus total dry matter production) and to the tubers (assuring that when the growth cycle is completed, most of the dry matter produced ends up in the tubers).

The plant dry matter production can be calculated with equation.

$$\delta W = LUE * F_{LINT} * PAR$$

Where LUE is the light use efficiency (g of plant dry matter produced per MJ of incident PAR), F_{LINT} (0-1) is the fraction of light intercepted radiation and PAR the sum of incident PAR (MJ/m^2).
We have found in the literature that the maximum value of light use efficiency for potato, when grown under optimum climate conditions in The Netherlands is 3.5 g MJ^{-1} of intercepted PAR radiation (Kooman, 1995). It is important to know which fraction of PAR is intercepted on average. The fraction of intercepted light increases until the crop reaches a certain coverage of the ground. We may assume, that in plant factory we want to reach full coverage, in order to use the maximum amount of light. Therefore, an average value of intercepted light for the whole cycle of 80 % seems possible in an indoor growing facility. Potato has a dry matter content of 20% (USDA, 1999). Finally, in a plant factory, it is possible to maintain always high CO_2 concentrations. Of course, the response of every species to high CO_2 concentration is different and depends on how optimum the other parameters are. Assuming that in a plant factory all is optimized, a 25% increase in yield due to high CO_2 levels would be a good estimation.

For potato we can assume as a good DLI to use a light intensity of 300 micromols/m^2 s during 18 hours per day, the total PAR on a whole year would be 300 micromols/m^2 s /4.57=65.6 W/m^2*3600 s/h*18 h/day*365 day/1e6 J/MJ=1553 MJ/m^2

Therefore, the total plant potato that can be potentially produced (fresh weight) is:
3.5 g/MJ *0.8* 2587MJ/m^2*0.8*1.25/0.2 g/g= **21,700 g/m**^{2}

This would be a good approximation to the potential amount of potatoes that could be harvested in a year in an indoor growing factory with an intensity of light of 300 micromols/m^2 s during 18 hours per day.

The amount of electricity required for the LED lamps, assuming and efficiency of 2.9 micromol/J: the 300 micromol /m^2s lamps would consume and electricity of 103.4 Watts/m^2. In a year, the lamps would function 6570 hours. The electricity use would be therefore **680 KWh/m^2** and for potato we can assume essentially the same set temperature set points as for tomato, since they belong to the same family. Therefore, we can estimate the cooling requirements for potato with the simulated light intensity to be **172 KWh/m^2**.

The rest of resource uses are included in.

6.2 Potato in greenhouse

If potato is cultivated in a greenhouse, part of the PAR radiation is provided by the sun. For potato, we can assume the same setting used for the tomato simulations with a simulated light intensity of 220 micromol/m^2s. Therefore, there resources used would be the same as in Table 16 and Table 17 and the potential potato yield in the greenhouse, assuming that total PAR sum of natural and artificial light in the whole cycle would be 1195 MJ/m^2 and 1205 MJ/m^2, for Keflavik and Akureyri, respectively, would be:

Keflavik: 3.5 g/MJ *0.8* 1195MJ/m^2*0.8*1.25/0.2 g/g= **16,730 g/m^2**
Akureyri: 3.5 g/MJ *0.8* 1205MJ/m^2*0.8*1.25/0.2 g/g= **16,870 g/m^2**

6.3 Rice in indoor farm

The record yields for rice have been obtained in Egypt. In Cairo, the average daily PAR integral is approximately 10 MJ/m^2. Since there are long day cultivars, we could provide 18 hours of light. We would need lamps to provide a light intensity of:

8.5 MJ/m^2*1e6 J/MJ/18/day/3600*4.57=600 micromols/m^2s

The maximum harvest index that can be achieved in rice is approximately 0.6. The radiation use efficiency is 2.2 g/MJ of intercepted PAR (Quero *et al.* 2019). We can assume an average radiation interception of 0.8. Dry matter content of rice is 87%.

In this way the harvestable rice, assuming a PAR light intensity of 600 micromols/m^2 s is: 2.2 g/MJ*0.8*3102.5MJ/m^2*0.6*1.25/0.87 g/g=**4,707 g/m^2**

The amount of electricity required for the LED lamps, assuming and efficiency of 2.9 micromol/J: the 600 micromol /m^2s lamps would consume and electricity of 206.9 Watts/m^2. In a year, the lamps would function 6570 hours. The electricity use would be therefore **1,360 KWh/m^2** but rice is a much more tropical crop which requires a day/night temperature regime of 28/22 °C. Although we do not have a rice crop model integrated in Kaspro, we can make as simulation using tomato since the maximum LAI of tomato is similar to that reached by rice (approximately 3.5), and from this simulation, obtain the cooling requirement. Therefore, we can estimate the cooling requirements for rice with the simulated light intensity to be **350 KWh/m^2**.

6.4 Rice in greenhouse

For rice, we need to simulate a light intensity of 450 micromol/m^2 s, which added to the amount of natural sunlight accounts for the same amount of light that we have simulated for the indoor farm.
Since rice has a much higher optimum growing temperature, simulations have been done increasing the heating set point to 28/22 °C for day and night period, respectively. The values of main resources use and predicted yield for both HPS and LED lamps are summarized in Table 33 and Table 34.

Table 34

Summary of main resource uses and predicted rice yield for Keflavik and Akureyri for HPS lamps.

	Energy used for heating (MJ m^{-2})*	Electricity used for artificial lighting(KWh/ m^2)	Hours lamps are on (h)	Amount of CO_2 used (kg/m^2)	Rice yield (kg/ m^2)
Keflavik-reference scenario	1332	1378	6213	38.8	4.7
Akureyri-reference scenario	1362	1391	6227	35.8	4.7

* This number already includes the extra energy required on an average year to deal with the snow in Keflavik and Akureyri

Table 35

Summary of main resource uses and predicted rice yield for Keflavik and Akureyri for LED lamps.

	Energy used for heating (MJ m^{-2})*	Electricity used for artificial lighting(KWh/ m^2)	Hours lamps are on (h)	Amount of CO_2 used (kg/m^2)	Rice yield (kg/ m^2)
Keflavik-reference scenario	2014	846	6213	34.1	4.7
Akureyri-reference scenario	2092	854	6229	31.2	4.7

* This number already includes the extra energy required on an average year to deal with the snow in Keflavik and Akureyri

6.5 Banana in indoor farm

For Banana, a light use efficiency of 1.63 g/MJ of intercepted PAR was found and an average fraction of intercepted radiation of 0.95 for a crop which is not on the first year (Chaves *et al.* 2009). Banana has a harvest index of 0.4 and a dry matter content of 0.2.

Banana is a tropical crop, which reaches the highest yield in tropical regions. Therefore we can assume a light intensity, same as for rice, of 600 micromols/m^2s , during 18 hours per day (3105 MJ/m^2):

1.63 g/MJ*0.950*3105MJ/m^2*0.4*1.25/0.2 g/g=**12,020 g/m^2**

The amount of electricity required for the LED lamps, assuming and efficiency of 2.9 micromol/J: the 600 micromol /m^2s lamps would consume and electricity of 206.9 Watts/m^2. In a year, the lamps would function 6570 hours. The electricity use would be therefore **1,360 KWh/m^2** . Banana is a much more tropical crop which has an optimum day/night temperature regime of 28/22 °C, same as rice. Although we do not have a banana crop model integrated in Kaspro, we can make as simulation using tomato since the maximum LAI of tomato is similar to that reached by banana (approximately 3), and from this simulation, obtain the cooling requirement. Therefore, we can estimate the cooling requirements for rice with the simulated light intensity to be **350 KWh/m^2**.

6.6 Banana in greenhouse

For banana grown in greenhouse, we can assume the same use of resources as for the rice (Table 23 and Table 24) and the production obtained for the plant factory.

6.7 Avocado in indoor farm

For avocado it has not been possible to find a study which estimated the light use efficiency under optimum growing conditions, but it has been possible to estimate it from the data provided in different studies. In Queensland (Australia) harvests of 2.6 kg/m^2 have been obtained for an optimum fraction of intercepted radiation of 0.8 (Menzel *et al.* 2014). In this region, the yearly PAR sum is approximately 3500 MJ/m^2. The harvest index can be assumed to be 0.45 and the dry matter content 0.3. Therefore, it is possible to estimate the LUE yield as:

LUE*0.8*3500 MJ/m^2*0.45/0.3 g/g=2600 g/m^2

LUE=0.62 g/MJ

However, in high density plantations yields of 3.5 kg/m^2 have been achieved. Assuming this type of High density plantation, the LUE would grow to 0.83 g/MJ

0.83 g/MJ*3500 MJ/m^2*0.8*0.45*1.25/0.3 g/g=**4,381 g/m**^{2}

For a plant factory in Iceland, in order to achieve the same light intensity and in Queensland, a light intensity of 675 micromols/m^{2}s, used for 18 hours per day would be required. The 675 micromol /m^{2}s lamps would consume and electricity of 233 Watts/m^2. In a year, the lamps would function 6570 hours. The electricity use would be therefore **1,531 KWh/m**^{2} . Avocado is a sub-tropical crop with an optimum day/night temperature regime of 25/20 °C. Although we do not have an avocado crop model integrated in Kaspro, we can make as simulation assuming a high density avocado plantation using tomato since the maximum LAI of a high density avocado plantation is similar to that reached by tomato (approximately 3), and from this simulation, obtain the cooling requirement. Therefore, we can estimate the cooling requirements for avocado with the simulated light intensity to be **413 KWh/m**^{2}.

6.8 Avocado in greenhouse

In the greenhouse, in order to meet the same amount of light received in the indoor farm, a light intensity of 525 micromol/m^{2}s. Since the temperature regime is 25/20 °C, we can simulate the tomato crop with the new temperature and light intensity settings. Results are summarized in Table 25 and Table 26.

Table 36

Summary of main resource uses and predicted avocado yield for Keflavik and Akureyri for HPS lamps.

	Energy used for heating (MJ m^{-2})*	Electricity used for artificial lighting(KWh/ m^2)	Hours lamps are on (h)	Amount of CO_2 used (kg/m^2)	Avocado yield (kg/m^2)
Keflavik-reference scenario	976	1607	6213	46.3	4.4
Akureyri-reference scenario	1019	1623	6228	42.5	4.4

* This number already includes the extra energy required on an average year to deal with the snow in Keflavik and Akureyri

Table 37
Summary of main resource uses and predicted avocado yield for Keflavik and Akureyri for LED lamps.

	Energy used for heating (MJ m^{-2})*	Electricity used for artificial lighting(KWh/ m^2)	Hours lamps are on (h)	Amount of CO_2 used (kg/m^2)	Avocado yield (kg/m^2)
Keflavik-reference scenario	1738	987	6213	40.8	4.4
Akureyri-reference scenario	1736	996	6231	38	4.4

* This number already includes the extra energy required on an average year to deal with the snow in Keflavik and Akureyri

6.9 Raspberry in indoor farm

For Raspberry, we have found in trials done in Wageningen University and Research Greenhouse Horticulture research station in Bleiswijk we have found values of LUE of 1.6 g of fresh weight fruit/mol of incident PAR radiation(personal communication). This LUE was in a greenhouse with CO_2 enrichment, so no need to increase by yield by 25%. An optimum daily light integral for raspberry is 20 mol/m^2 day. This amount of light can be obtained with 350 micromols/m^2 day with a duration of the day time period of 16 hours. In a year, this light intensity sums 7,358 mol of PAR/m^2.

1.6 g/mol*7,358 mol/m^2=**11,400 g/m**^{2}

The amount of electricity required for the LED lamps, assuming and efficiency of 2.9 micromol/J: the 350 micromol /m^2s lamps would consume and electricity of 121 Watts/m^2. In a year, the lamps would function 5,840hours. The electricity use would be therefore **705 KWh/m**^{2} . Raspberry is a cold crop with an optimum day/night temperature regime of 16/10 °C. Although we do not have a raspberry crop model integrated in Kaspro, we can make as simulation assuming that raspberry can achieve a maximum LAI similar to that of tomato (approximately 3), and from this simulation, obtain the cooling requirement. Therefore, we can estimate the cooling requirements for avocado with the simulated light intensity to be **174 KWh/m**^{2}

6.10 Raspberry in greenhouse

For Raspberry grown in the greenhouse, we can simulate a light intensity of 200 micromol/m^2s (the solar light contributes with part of the radiation that would match the total light provided in an indoor farm) and a temperature regime of 16/10 °C. Results of main resource use is summarized in Table 37 and Table 38.

Table 38
Summary of main resource uses and predicted raspberry yield for Keflavik and Akureyri for HPS lamps.

	Energy used for heating (MJ m^{-2})*	Electricity used for artificial lighting(KWh/ m^2)	Hours lamps are on (h)	Amount of CO_2 used (kg/m^2)	Raspberry yield (kg/m^2)
Keflavik-reference scenario	912	609	6127	36.2	9.9
Akureyri-reference scenario	1002	613	6133	32	9.8

* This number already includes the extra energy required on an average year to deal with the snow in Keflavik and Akureyri

Table 39
Summary of main resource uses and predicted raspberry yield for Keflavik and Akureyri for LED lamps.

	Energy used for heating (MJ m^{-2})*	Electricity used for artificial lighting(KWh/ m^2)	Hours lamps are on (h)	Amount of CO_2 used (kg/m^2)	Raspberry yield (kg/m^2)
Keflavik-reference scenario	1325	374	6131	33.3	9.8
Akureyri-reference scenario	1425	377	6148	29.5	9.7

* This number already includes the extra energy required on an average year to deal with the snow in Keflavik and Akureyri

6.11 Sweet pepper in indoor farm

Sweet pepper has a LUE of 3.8 g/MJ of incident PAR in a Dutch greenhouse, a harvest index of 60%, a dry matter content of 8% and an average fraction of intercepted PAR for the whole cycle of 80% (Marcelis *et al.* 2006). The optimum daily light integral for sweet pepper is 30 mol/m^2 s, which can be achieved with 400 micromol/m^2 s, which in a whole year would be an accumulated PAR of 2,070 MJ/m^2. Therefore, the potential yield in a plant factory would be:

3.8 g/MJ*2070 MJ/m^2*0.8*0.6/0.08 g/g=**47,196 g/m**^{2}

The amount of electricity required for the LED lamps, assuming and efficiency of 2.9 micromol/J: the 400 micromol /m^2s lamps would consume and electricity of 138 Watts/m^2. In a year, the lamps would function 6,570 hours. The electricity use would be therefore **680 KWh/m**^{2} and for sweet pepper we can assume essentially the same set temperature set points as for tomato, since they belong to the same family. Therefore, we can estimate the cooling requirements for sweet pepper with the simulated light intensity to be **238 KWh/m**^{2}.

6.12 Sweet pepper in greenhouse

For a sweet pepper in the greenhouse we may assume the same settings in the greenhouse that for the tomato simulation with a light intensity of 220 micromol/m^2s. Therefore we may assume the same use of resources as that shown in Table 16 and Table 17.

The potential yield for both Keflavik and Akureyri in a greenhouse would be:

Keflavik: 4.5 g/MJ*1196 MJ/m^2*0.8*0.6/0.08 g/g=**32.3 g/m**^{2}
Akureyri: 4.5 g/MJ*1205 MJ/m^2*0.8*0.6/0.08 g/g=**32.5 g/m**^{2}

6.13 Wheat in indoor farm

Wheat has a LUE of 2.2 g/MJ of incident PAR (Marcos, 2000). The maximum harvest index for wheat can be estimated in 60% for some cultivars, the average fraction of intercepted PAR is around 70% and the dry matter content is 90%. Therefore, the potential production in a plant factory would be, assuming a light intensity of 600 micromol/m^2s (yearly sum of 3019 MJ/m^2):

2.2 g/MJ*3105 MJ/m^2*0.70*0.6/0.9=**3,187 g/m**^{2}

The amount of electricity required for the LED lamps, assuming and efficiency of 2.9 micromol/J: the 600 micromol /m²s lamps would consume and electricity of 207 W/m². In a year, the lamps would function 6570 hours. The electricity use would be therefore **1,359 KWh/m²** and for wheat we can assume optimum temperature set points of 20/15 °C for day/night. We can estimate the cooling requirements for wheat assuming the same crop tomato model but increasing maximum LAI to 10. with the simulated light intensity to be **379.1 KWh/m²**.

6.14 Wheat in greenhouse

For wheat grown in the greenhouse, we can simulate a light intensity of 420 micromol/m²s (the solar light contributes with a part of the radiation that would match the total light provided in an indoor farm) and a temperature regime of 20/15 °C. The yield can be assumed equal to that in the indoor farm. Results of main resource use is summarized in Table 39 and Table 40. The larger energy and CO_2 use for wheat is caused by the much higher LAI of wheat, which makes transpiration to rise very high, demanding a larger amount of energy due to larger ventilation opening for humidity control.

Table 40
Summary of main resource uses and predicted wheat yield for Keflavik and Akureyri for HPS lamps.

	Energy used for heating (MJ m⁻²)*	Electricity used for artificial lighting(KWh/m²)	Hours lamps are on (h)	Amount of CO_2 used (kg/m²)	Wheat yield (kg/m²)
Keflavik-reference scenario	2260	1286	6213	52.7	3.2
Akureyri-reference scenario	2149	1299	6228	50.5	3.2

* This number already includes the extra energy required on an average year to deal with the snow in Keflavik and Akureyri

Table 41
Summary of main resource uses and predicted wheat yield for Keflavik and Akureyri for LED lamps.

	Energy used for heating (MJ m⁻²)*	Electricity used for artificial lighting(KWh/m²)	Hours lamps are on (h)	Amount of CO_2 used (kg/m²)	Wheat yield (kg/m²)
Keflavik-reference scenario	2644	789	6213	51.6	3.2
Akureyri-reference scenario	2708	797	6231	50.3	3.2

* This number already includes the extra energy required on an average year to deal with the snow in Keflavik and Akureyri

7 Summary use of resources and yields of all analysed scenarios for the two studied locations

Table 42

Summary of main resources use and potential yields for all simulations performed.

Crop	Location	Cultivation system	Type of lamp	Light intensity (micromole/m²/s)	Heating set points (day °C/night °C)	Energy used for cooling (KWh/m²)	Energy for heating (MJ m⁻²)/(m³ hot water/m²) *	Electricity for artificial lighting (KWh/m²)	Water (L/m²)	CO_2 (kg/m²)	Predicted yield (kg/heads*/m²)
Tomato	Keflavik	Greenhouse	HPS	220	complex	-	1442	542	1028	32.2	105.6
				250			1358	615	1088	34.6	110.7
				280			1257	678	1115	35.8	109.5
			LED	220			1906	333	951	30.5	105.5
				250			1840	378	983	32.2	109.2
				280			1787	419	1009	33.5	108.9
	Akureyri		HPS	220			1599	547	942	28.3	104.1
				250			1500	620	1000	30.2	112.4
				280			1423	686	1044	32	111.8
			LED	220			2085	336	869	26.9	104
				250			2014	382	902	28.5	107.9
				280			1746	424	924	29.8	108.3
Lettuce	Keflavik			200	12/9		485	520	723	39.1	155
					15/12		944	520	817	36.6	159
					18/15		1480	520	930	33.9	159
				230	12/9		441	574	754	39.9	161
					15/12		875	574	846	37.4	165
					18/15		1395	574	958	34.5	165
				260	12/9		419	600	770	39	163

Crop	Location	Cultivation system	Type of lamp	Light intensity (micromole/m²/s)	Heating set points (day °C/night °C)	Energy used for cooling (KWh/m²)	Energy for heating (MJ m⁻²)/(m³ hot water/m²) *	Electricity for artificial lighting (KWh/m²)	Water (L/m²)	CO_2 (kg/m²)	Predicted yield (kg/heads*/m²)
					15/12		846	600	860	37.4	166
					18/15		1360	600	972	34.6	166
			LED	200	12/9		765	321	631	37.6	152
					15/12		1336	321	739	35.7	159
					18/15		1920	321	858	32.8	160
				260	12/9		717	355	648	38	159
					15/12		1276	355	755	36	165
					18/15		1854	355	874	33.4	166
				230	12/9		694	372	656	37.7	160
					15/12		1248	372	762	36.1	166
					18/15		1827	372	880	33.5	167
			HPS	200	12/9		538	525	705	35.0	155
					15/12		1047	525	797	32.7	159
					18/15		1641	525	907	30.3	159
				230	12/9		489	579	736	35.7	161
					15/12		970	579	825	33.5	165
					18/15		1547	579	935	30.9	165
				260	12/9		465	606	751	34.9	163
					15/12		938	606	839	33.5	166
					18/15		1508	606	948	30.9	166
				200	12/9		807	324	616	33.6	152
					15/12		1410	324	721	31.9	159
					18/15		2026	324	837	29.3	160
				230	12/9		757	358	632	34.0	159

Crop	Location	Cultivation system	Type of lamp	Light intensity (micromole/m^2/s)	Heating set points (day °C/night °C)	Energy used for cooling (KWh/m^2)	Energy for heating (MJ m^{-2})/(m^3 hot water/m^2) *	Electricity for artificial lighting (KWh/m^2)	Water (L/m^2)	CO_2 (kg/m^2)	Predicted yield (kg/heads*/m^2)
					15/12		1346	358	737	32.2	165
					18/15		1956	358	853	29.9	166
				260	12/9		732	375	640	33.7	160
					15/12		1317	375	743	32.3	166
					18/15		1928	375	859	30.0	167
Tomato	Keflavik	Indoor farm	LED	350	23/19	201	54.9	777	944	18.2	129
				450		268	51	1000	1170	21.9	143
				550		343	49	1221	1394	25.5	151
Lettuce				230	21/18	58.4	109	516	562	17.3	161
				330		92.4	49.8	741	749	21.7	198
				430		153	38.4	965	987	26	232
Potato		Indoor farm	LED	300	complex	172	47	680	809	15.6	21.7
		Greenhouse		220		-	1906	333	951	30.5	16.7
	Akureyri						2085	336	869	26.9	16.9
	Keflavik		HPS				1442	542	1028	32.2	16.7
	Akureyri						1599	547	942	28.3	16.9
Rice	Keflavik	Indoor farm	LED	600	28/22	350	224	1360	-	23	4.7
		Greenhouse		450		-	2014	846	-	34.1	4.7
	Akureyri						2093	854		31.2	4.7
	Keflavik		HPS				1332	1378		38.8	4.7
	Akureyri						1362	1391		35.8	4.7
Banana	Keflavik	Indoor farm	LED	600		350	224	1360		23	12
		Greenhouse		450		-	2014	846		34.1	12
	Akureyri						2093	854		31.2	12

Crop	Location	Cultivation system	Type of lamp	Light intensity (micromole/m²/s)	Heating set points (day °C/night °C)	Energy used for cooling (KWh/m²)	Energy for heating (MJ m⁻²)/(m³ hot water/m²) *	Electricity for artificial lighting (KWh/m²)	Water (L/m²)	CO_2 (kg/m²)	Predicted yield (kg/heads*/m²)
	Keflavik		HPS				1332	1378		38.8	12
	Akureyri						1362	1391		35.8	12
Avocado	Keflavik	Indoor farm	LED	675	25/20	413	157.5	1531		25.8	4.4
		Greenhouse		525		-	1738	987		40.8	4.4
	Akureyri						1736	996		38	4.4
	Keflavik		HPS				976	1607		46.3	4.4
	Akureyri						1019	1623		42.5	4.4
Rasberry	Keflavik	Indoor farm	LED	350	16/10	174	0.06	705		12.2	11.4
		Greenhouse		200		-	1325	374		33.3	11.4
	Akureyri						1425	377		29.5	11.4
	Keflavik		HPS				912	609		36.2	11.4
	Akureyri						1002	613		32	11.4
Sweet	Keflavik	Indoor farm	LED	400	complex	238	238	680		19.5	47.2
pepper		Greenhouse		220		-	1906	333	951	30.5	32.3
	Akureyri						2085	336	869	26.9	32.5
	Keflavik						1442	542	1028	32.2	32.3
	Akureyri						1599	547	942	28.3	32.5
Wheat	Keflavik	Indoor farm	LED	600	20/15	379	67	1359		56	3.2
		Greenhouse		420		-	1870	789		51.6	3.2
	Akureyri						2177	797		50.3	3.2
	Keflavik		HPS				1486	1286		52.7	3.2
	Akureyri						1618	1299		50.5	3.2

(*The values of energy for heating include the energy required for melting of the snow;**For lettuce, the yield is measured in heads of 330 g per square meter).

8 Market assessment

8.1 Rice

8.1.1 Introduction

Most rice tends to be eaten where it is produced and so does not enter international markets. Rice is mostly produced in Asia, but also many other regions have increased production since the consumption is increasing. However, consumption has grown faster than production. As a result, many countries must import their rice.

The following rice varieties are of significance concerning shipment and transport:
- Paddy rice: unprepared rice which is still firmly enclosed in its glumes.
- Brown rice: has had its glumes removed but is otherwise unprepared. The glumes are removed in the exporting countries by hulling. The majority of the silver skin is still attached to the hulled rice grain. Brown rice is shipped only in small batches.
- White or polished rice: prepared rice which has had the silver skin and seed coat beneath it removed by polishing.
- Cargo rice: rice which is provided for maritime transport and consists of 80% white rice and 20% paddy rice. Due to this mixing ratio, the rice remains drier and harder during maritime transport, because the coarse-hulled paddy grains cause loosening and thus better airing of the rice batches. For this reason, cargo rice is the least susceptible to damage.

In the international rice trade, a relatively small number of exporting countries interact with a large number of importing countries. In the international market, consumer interest in speciality rice is growing, like aromatic rice. Consumers are drawn to specific Asian aromatic varieties of rice (e.g. basmati rice), as well as to varieties that are suitable for traditional dishes such as sushi, risotto or paella. Brown rice has also increased in popularity thanks to its health benefits.

During the milling processes, the hulls are removed from the raw grain to reveal whole brown rice, which is then usually milled further to remove the bran layer, resulting in white rice. The husk is often used for other purposes such as energy consumption. Rice is normally transported in bulk by ship. Bulk containers, subject to appropriate pre-drying of the product to approx. 12–13%, or passively ventilated containers (www.tis-gvd.de).

8.1.2 Markets

Italy is the major rice producer in Europe with 1.5 million tonnes in 2018, which was 37% of total European rice production (FAOStat). A suitable climate for rice production is the major reason for its domination. Also, the consumption of rice in Italy is high. Rice consumption per capita reached 8.7 kg in 2017 in Italy, according to FAOStat. However the total domestic availability of rice is almost 27 kg per capita, see table below. A lot of rice is also reexported and this will give opportunities for the import of rice from Iceland.

Costa Rica appears to be an interesting market for rice. The current consumption of milled rice amounted to 232,192 tonnes in 2016/2017, as compared to 240,749 tonnes in 2015/2016, according to a recent USDA report (2018) on the Cost Rican rice market. Rice consumption, which is high on a per capita basis, is expected to range from 230,000 tonnes to 235,000 tonnes in 2018/2019. During the 2016/2017 crop year, local rice production covered 56% of consumption, while serious volumes of imported rice supplied the rest. Per-capita consumption for 2016/2017 was 47.5 kg. Although total rice consumption declined national production is not sufficient, so import remains key to meet local demand. Of the rice sold in the country, 43% of total sales is cargo rice (80% whole grain and 20% broken grain).

China is among the major producers of rice worldwide. However, China also imports substantial volumes of rice to meet domestic demand. So national availability levels of rice are among the highest in the world.

Other countries that turned out to be interesting, based on the market selection model are Colombia, Spain, Nicaragua, Portugal and Pakistan. All countries are involved in rice production but also rely on serious import volumes to meet domestic market demands.

Table 43
Various indicators for rice.

	ITA	CRI	CHN	COL	ESP	NIC	PRT	PAK
Population (1,000)	60,627.3	4,950.0	1,421,021.8	48,909.8	46,692.9	6,384.8	10,256.2	212,228.3
Population development (%)	0.3	1.1	0.5	1.2	-0.1	1.4	-0.4	2.3
Availability, excluding export (tonnes)	1,609,260	308,674	211,903,237	3,258,773	839,328	548,151	193,207	10,794,943
Availability development (%)	0.4	-1.7	1.2	12.4	-1.4	1.4	0.1	3.0
Import price (USD/ kg)	0.4	0.5	0.6	0.4	0.3	0.4	0.3	0.2
Import quantity (tonnes)	43,388.7	130,080.0	18,237.0	82,679.5	13,079.7	127,806.0	23,302.3	44,365.7
Import development (%)	12.8	9.2	2.2	76.0	22.3	2.7	2.0	48.6
GDP (USD per capita)	34,318.4	12,026.5	9,770.8	6,651.3	30,523.9	2,028.9	23,145.7	1,472.9
Cost of cross border trade (USD)	1,145.0	1,225.0	925.3	2,632.0	1,400.0	1,403.1	925.0	1,255.0

Source: UNComtrade, FAOSTAT, World Bank

8.1.3 Wholesale prices and cost of transportation

For most countries, FAO provides good insight into the price development of rice-producing countries. Rice is often trade per tonne and prices seems to be a bit lower. However certain (aromatic) varieties can get a price premium up to 100% of common varieties (Giraud, 2013). In the table below we present the different prices for common rice observed in the market.

Table 44
Rice wholesale prices in USD per kg of selected countries (based on a 3 year average).

	Price	Comments	Source
Italy	0.43	Producer prices based on a 3 year average	FAOSTAT
Costa Rica	0.49	Producer prices based on a 3 year average	FAOSTAT
China	0.56	Producer price 2016	FAOSTAT
Colombia	0.38	Producer price 2016	FAOSTAT
Spain	0.33	Producer prices based on a 3 year average	FAOSTAT
Nicaragua	0.95	Wholesale price	FAO FPMA PROXY TAKEN FROM EL SALVADOR
Portugal	0.33	Producer prices based on a 3 year average	FAOSTAT
Pakistan	0.19	Producer price 2016	FAOSTAT

Source: FAOSTAT

The different costs elements are presented below. Rice is transported as bulk cargo or as break-bulk cargo in bags (e.g. 100 kg bags of woven jute fabric). Rice is also packaged in smaller 500 g plastic bags and transported in cartons.

In the transportation sector, a Stowage Factor (SF) is often considered. This relates to the volume occupied by one unit of mass (weight) when stowed in cargo space. For rice, the SF is 1.36 m/3 a tonne for bulk transport. So this implies that a 40 ft standard container will have a load of 24.8 tonnes of rice.

Table 45

Transportation costs from Iceland to selected countries.

Destination	Port	min	max	average	Container load (kg)	Price per kg USD
To Italy	Gioia Tauro	986	1,090	1,038	27,750	0.037
To Costa Rica	Limon	2,221	2,455	2,338	27,750	0.084
To China	Rotterdam	393	434	414	27,750	0.015
	Rotterdam to Shanghai	1,400	1,600	1,500	27,750	0.054
	Total	1,793	2,034	1,914	27,750	0.069
To Colombia	Cartagena	2,840	3,139	2,990	27,750	0.108
To Spain	Rotterdam	393	434	414	27,750	0.015
	From Rotterdam to Santander by ship	913	1,009	961	27,750	0.035
	Total	1,306	1,443	1,375	27,750	0.050
To Nicaragua	Corinto	3,495	3,863	2,336	27,750	0.084
To Portugal	Lisbon	1,987	2,197	2,092	27,750	0.075
To Pakistan	Karachi	2,877	3,179	3,028	27,750	0.109

*(data still missing Source: World Freight Rates; China to Rotterdam is sourced from Hapag Loyd

8.1.4 Import levies

Rice produced in Iceland are exempted from any import levy in the EU due to a preferential tariff agreed in 1994. Nicaragua and Costa Rica also have free trade agreements. However, for exporting rice to Colombia (5%), China (65%) and Pakistan (3%) different levies are applied.

8.1.5 Synthesis

Production of rice in Iceland and shipping towards the selected international markets is profitable considering the current market prices in most countries. For the calculated cost price for production, we used the cost price for greenhouse production in Akureyri which is the location where production cost per kg is the lowest.

Table 46
Results rice in USD per kg.

	Calculated cost price for production	Transportation cost	Import levy	Total cost price	Average wholesale price	Margin
Nicaragua	26.3	0.08		26.38	0.95	-25.43
Costa Rica	26.3	0.08		26.38	0.49	-25.89
Italy	26.3	0.04		26.34	0.43	-25.91
Spain	26.3	0.05		26.35	0.33	-26.02
Colombia	26.3	0.11	0.02	26.43	0.38	-26.05
Portugal	26.3	0.08		26.38	0.33	-26.05
China	26.3	0.05	0.36	26.71	0.56	-26.15
Pakistan	26.3	0.11	0.01	26.44	0.19	-26.25

8.2 Potato

8.2.1 Introduction

Only a small share of potatoes is traded internationally. The trade in fresh, seed and frozen processed potatoes made up around 7% of total potato production in 2017. The remainder is consumed and processed locally. Some key observation about the international potato trade:

- Frozen processed potato trade grew from around 4 million tonnes to more than 7 million tonnes over the last ten years, driven by an increase in consumption in Asia, the Middle East, and Latin America.
- Dutch exports dominate the trade in seed potatoes, with a market share of over 50% of global trade.
- International trade in fresh potatoes is limited but has increased substantially, with trading seen by various North African and Asian countries such as Egypt and China.

8.2.2 Markets

A growing global population and increasing demand for frozen processed potatoes drive the demand for high-quality seed potatoes in the near future. This supports the demand for (seed) potatoes. The table below provides an overview of the key markets and some of the main characteristics. Belgium, the Netherlands, Germany, Denmark, Austria, the USA, France and Ireland are key potato markets due to a high level of consumption per capita, but also due to high level of imports for re-export or processing.

Processed potatoes
Whereas potatoes grow in almost every country around the world, there are only a few countries that have a significant frozen processed potato sector (e.g. Belgium, the Netherlands, and the USA).

Cost-effective production of frozen processed potato products requires a year-round supply of high-quality potatoes. To achieve the yield necessary for processing, potato growers in North America and Northwestern Europe invested in knowledge, mechanization, storage, and irrigation. The prerequisite of yield, quality, and year-round supply means that the barriers to entry for frozen processed potatoes are high.

Seed potatoes
Over the last ten years, the Dutch seed potato sector increased exports by 300,000 tonnes, to almost 1 million tonnes in 2017. Other European countries such as France and Germany also saw their exports increase. With an export share of over 50%, the Dutch seed potato growers are a very important source of high-quality seed potatoes. Dutch seed potatoes are mainly exported to countries in North Africa, the Middle East, and Europe.

Destination countries in North Africa and the Middle East often lack the infrastructure to produce and store high-quality seed potatoes, making these countries dependent on imports. Within Europe, Dutch seed potato exports have benefited from growth in the frozen processed potato industry, which requires specialized potato varieties.

Table 47

Market selection indicators

	BEL	NLD	DEU	DNK	AUT	USA	FRA	IRL
Population (1,000)	11,482.2	17,021.3	83,124.4	5,752.1	8,819.9	327,096.3	64,842.5	4,753.3
Population development (%)	0.6	0.3	0.4	0.4	0.7	0.7	0.4	0.6
Availability, excluding export (tonnes)	6,119,388.3	8,651,766.5	11,033,013.7	2,077,089.0	887,414.5	20,891,550.0	8,055,242.0	451,476.0
Availability development (%)	3.1	-0.1	-1.0	4.0	1.1	1.0	1.4	0.9
Import price (USD/ kg)	0.2	0.2	0.2	0.3	0.2	0.2	0.4	1.2
Import quantity (tonnes)	2,497,756.7	1,688,657.0	562,047.0	99,828.3	177,084.0	395,837.0	304,073.5	69,276.0
Import development (%)	10.0	0.6	-1.6	1.8	10.2	1.8	-2.5	2.3
GDP (USD per capita)	46,556.1	52,978.4	48,195.6	60,595.6	51,512.9	62,641.0	41,463.6	77,449.7
Cost of cross border trade (USD)	1,400.0	975.0	1,050.0	745.0	1,215.0	1,390.5	1,445.0	1,220.0

Source: UNComtrade, FAOSTAT, World Bank

8.2.3 Wholesale prices and cost of transportation

Potato prices are very much demand and supply-driven. Especially wheatear influences have a serious impact on potato production. Sometimes due to bad weather production is seriously low resulting in higher prices.

Table 48

Potato prices of selected countries in USD per kg.

	min	max	average	Comments	Source
Belgium	0.13	0.27	0.20	Farm gate price	FAOSTAT
Netherlands	0.18	0.19	0.19	Farm gate price	FAOSTAT
Germany	0.20	0.22	0.21	Farm gate price	FAOSTAT
Denmark	0.25	0.29	0.27	Farm gate price	FAOSTAT
Austria	0.16	0.25	0.21	Farm gate price	FAOSTAT
USA	0.19	0.20	0.19	Farm gate price	FAOSTAT
France	0.27	0.52	0.40	Farm gate price	FAOSTAT
Ireland	0.18	0.19	0.18	Farm gate price	NL price as proxy sourced from FAOSTAT

Potatoes are mainly transported in wide-meshed bags but are sometimes also transported in perforated plastic bags, crates, cartons and baskets. Their high water content also makes them particularly sensitive to bruising and they must therefore be handled with care.

In the case of potatoes loaded in bags, stack heights of up to eight bags are desirable where possible (maximum stack height: 12 – 13 bags), to ensure adequate airing of the cargo block. For this reason, „ventilation trenches" should also be provided, which must be protected from possible blockage by slipping bags.

If the potatoes are loaded in boxes or cartons, these must be arranged in such a way that spaces between packages or pallets are filled, to prevent slippage or tipping. By selecting the correct packaging size or cargo unit (area module or area module multiple), holds can be tightly loaded (without spaces). A standard 40ft reefer container contains about 27 tonnes of potatoes (1,100 25kg bags or 20 pallets with 55 pallets with 25kg each). The cost of transportation to most European countries is limited to a maximum of 0.03 USD per kg. The costs of exporting potatoes to the United States is 10 times higher and account for almost 0.30 USD per kg.

Table 49

Transportation costs from Iceland to selected countries for potatoes in cooled containers with 27 tonnes..

Destination	Port	min	max	average	Container load (kg)	Price per kg USD
To Belgium	Antwerp	719	795	757	27,000	0.028
To the Netherlands	Rotterdam	707	760	734	27,000	0.027
To Germany	Hamburg	713	788	751	27,000	0.028
To Denmark	via Hamburg	713	788	751	27,000	0.028
To Austria	via Rotterdam	707	760	734	27,000	0.027
To USA	New York	5,736	6,340	6,038	27,000	0.224
To France	via Antwerp	719	795	757	27,000	0.028
To Ireland*	Dublin	500	700	600	27,000	0.022

*(Transportation cost for Ireland is an estimation since there is no public data available. Source: worldfreightrates.com

8.2.4 Import levies

Potatoes produced in Iceland and exported to the European Union are exempted from any import levy due to a preferential tariff agreed in 1994. For export to the United States, a fee of 0.5 USD per kg is applied as import levy.

8.2.5 Synthesis

Production of potatoes in Iceland and shipping towards the selected international markets is not profitable considering the current market prices. For the calculated cost price for production, we used the cost price for greenhouse production in Akureyri which is the location where production cost per kg is the lowest.

Table 50
Results potato in USD per kg.

	Calculated cost price for production	Transportation cost	Import levy	Total cost price	Average wholesale price	Margin
France	5.14	0.03		5.16	0.40	-4.77
Denmark	5.14	0.03		5.16	0.27	-4.90
Germany	5.14	0.03		5.16	0.21	-4.95
Austria	5.14	0.03		5.16	0.21	-4.96
Belgium	5.14	0.03		5.16	0.20	-4.97
Ireland	5.14	0.02		5.16	0.18	-4.97
The Netherlands	5.14	0.03		5.16	0.18	-4.98
USA	5.14	0.22	0.50	5.86	0.19	-5.66

8.3 Banana

8.3.1 Introduction

Banana is one of the most eaten fruits in the EU and the United States. Bananas are the number one fresh fruit imported into Europe, whose trade is in large part dominated by multinationals such as Chiquita, Fyffes and Dole. Ecuador, Colombia and Costa Rica are the main suppliers of bananas but new exporting countries have been entering the banana trade, including Guatemala, Honduras, Nicaragua, Peru (with organic bananas) and Ghana (with fair-trade bananas). At the same time, diseases affecting banana plantations may force buyers to diversify their sourcing origins.

8.3.2 Markets

Belgium re-exports high volumes, and it functions as the logistics hub for bananas in Europe. The Netherlands is a key European trade hub for fruit and vegetables from producing countries and is gaining importance for the trade of bananas. From the port of Rotterdam, the main entry point, Dutch and international traders distribute fresh produce to the rest of Europe.

The United Arab Emirates is also a promising market with a serious increase in banana consumption. Major suppliers are the Philippines and Ecuador.

Table 51

Market selection indicators.

	NLD	SVN	ARE	USA	DEU	BEL	FIN	GBR
Population (1,000)	17,021.3	2,076.4	9,487.2	327,096.3	83,124.4	11,482.2	5,511.4	67,141.7
Population development (%)	0.3	0.2	0.8	0.7	0.5	0.6	0.3	0.7
Availability, excluding export (tonnes)	726,337.5	78,261.0	180,131.0	4,760,432.3	1,326,995.3	1,293,564.0	112,793.0	1,093,398.0
Availability development (%)	39.3	15.7	25.0	1.1	0.1	-0.5	10.7	-0.1
Consumption per person (kg per capita)	42.7	37.7	19.0	14.6	16.0	112.7	20.5	16.3
Import price (USD/kg)	0.9	1.0	0.8	2.2	2.7	0.8	1.1	0.5
Import quantity (tonnes)	726,337.5	3,592,932.5	179,931.0	4,756,548.0	1,326,995.3	1,293,564.0	112,793.0	1,093,398.0
Import development (%)	19.7	921.2	12.5	0.7	0.1	-0.3	5.4	-0.1
GDP (USD per capita)	52,978.4	26,234.0	43,004.9	62,641.0	48,195.6	46,556.1	49,960.2	42,491.4
Cost of cross border trade (USD)	975.0	830.0	962.3	1,390.5	1,050.0	1,400.0	627.0	1,053.0

Source: UNComtrade, FAOSTAT, World Bank

8.3.3 Wholesale prices and costs of transportation

It can be stated that the EU price is reflected by the price traded on the Dutch fresh market. However, this does not include Spain, since they have their domestic production in the Canarias of bananas which have a different taste and as a result a different price setting. See also Annex 1 for seasonality patterns the banana prices in the United States, the Netherlands and Spain as reported by USADA.

Table 52

Banana wholesale prices for selected countries in USD per kg.

Indicator	min	max	average	Comments	Source
Slovenia	0.70	1.05	0.88	NL Price wholesale price	USADA
Netherlands	0.70	1.05	0.88	NL Price wholesale price	USADA
United Arab Emirates	0.60	0.60	0.60	Import price, including plantain	Comtrade
United States	1.30	1.40	1.35	NY wholesale price	USADA
Germany	0.70	1.05	0.88	NL Price wholesale price	USADA
Belgium	0.70	1.05	0.88	NL Price wholesale price	USADA
Finland	0.70	1.05	0.88	NL Price wholesale price	USADA
France	0.70	1.05	0.88	NL Price wholesale price	USADA

Bananas are usually packed in boxes with a net weight of 19.5 kg. Without the palletizing process, a container can transport 1,200 boxes and using the process, the container can be loaded with 1,080 boxes. The total weight of a container load is then 23.4 tonnes of produce.

Table 53

Transportation costs from Iceland to selected countries.

Destination	Port	min	max	average	Container load (kg)	Price per kg USD
To Slovenia	Rotterdam	707	760	734	23,400	0.03
	From Rotterdam to Lubljana by truck	613	678	646	23,400	0.03
	Total	1,320	1,438	1,379		0.06
To the Netherlands	Rotterdam	707	760	734	23,400	0.03
United Arab Emirates	Rotterdam	707	760	734	23,400	0.03
	King Abdul Aziz Port, Saudi Arabia	1,670	1,845	1,758	23,400	0.08
	Total	2,377	2,605	2,491		0.11
To the United States	New York	5,736	6,340	6,038	23,400	0.26
To Germany	Hamburg	713	788	751	23,400	0.03
Belgium	Antwerp	719	795	757	23,400	0.03
Finland	Helsinki	739	817	778	23,400	0.03
France	via Antwerp	719	795	757	23,400	0.03

Source: World Freight Rates

8.3.4 Import levies

Banana produced in Iceland are exempted from any import levy in the EU due to a preferential tariff agreed in 1994. Also, the United States and the Emirates do not apply any trade remedy on bananas.

8.3.5 Synthesis

Production of bananas in Iceland and shipping towards the selected international markets is not profitable considering the current market prices. For the calculated cost price for production, we used the cost price for greenhouse production in Akureyri which is the location where production cost per kg is the lowest.

Table 54
Results banana in USD per kg.

	Calculated cost price for production	Transportation cost	Import levy	Total cost price	Average wholesale price	Margin
Slovenia	12.72	0.06		12.78	0.88	-11.90
The Netherlands	12.72	0.03		12.75	0.88	-11.88
United Arab Emirates	12.72	0.11		12.83	0.60	-12.23
United States	12.72	0.26		12.98	0.88	-12.10
Germany	12.72	0.03		12.75	0.88	-11.88
Belgium	12.72	0.03		12.75	0.88	-11.88
Finland	12.72	0.03		12.75	0.88	-11.88
France	12.72	0.03		12.75	0.88	-11.88

8.4 Fresh raspberry

8.4.1 Introduction

Raspberries can be supplied fresh and frozen. For this study, we considered fresh raspberries only. They are becoming a standard product for most supermarkets. The United Kingdom and Germany maintain the highest total import of fresh berries, both over 50 thousand tonnes. The United Kingdom leads in cranberries, while Germany imports more raspberries. The Netherlands is the third-largest importer thanks to its position as a trade hub. Spain is an upcoming importer of fresh berries (from neighbouring countries), both for the internal market but also for the re-export.

Raspberries are often produced in the open field or simple plastic tunnels and therefore prices fluctuate depending on the weather conditions. It is important to note that consumers are becoming more conscious about seasonal fruit and there is a growing preference for local fruit. Retailers have responded to this by emphasising and promoting locally produced berries. Although part of the berry demand is met by imports, the seasonal fruit trend can pose a risk to the further growth of imports from long-distance suppliers.

8.4.2 Markets

Spain and Portugal face competition from Portugal and Morocco. The Spanish raspberry season starts always a bit early compared to countries in Northern Europe. Prices are under pressure and the demand is low due to the large volumes from Spain, Morocco and Portugal. According to Spanish exporters, competition from Morocco and Portugal is stronger this year. Moreover, there is less room for Spanish production due to the start of local production season during summer.

At the end of the season, cheap berries from Morocco is there for Spain until July. Then there is no longer place for Spanish production on the market, and that also applies to neighbouring Portugal.

Germany has some serious local production of raspberry. Mainly in the open field and simple tunnels. Besides this, they source large volumes from Spain and Portugal.

Across the United Kingdom, the planted area for soft fruit increased by 8% between 2014 and 2016. Consumption Soft fruit consumption takes many forms including smoothies, fruit salads and as ingredients in other products including fresh fruit used to decorate cakes and pastries. The rise in fruit-flavoured ciders has also been a factor in the industry's expansion. Most raspberries and strawberries are consumed fresh.

The United States is an important market for berries. There is serious local production, but also iports from Mexico are dominant. Especially in California, serious supplies arrive from Mexico. The raspberry market is very volatile, with prices dropping to 10-12 USD per kilogram and suddenly rising again to 18-24 USD per kilogram, according to market developments mentioned on Fresh Plaza[2].

Table 55

Market selection indicators.

	ESP	DEU	USA	GBR	NLD	BEL	PRT	CHE
Population	46,692.9	83,124.4	327,096.3	67,141.7	17,021.3	11,482.2	10,256.2	8,525.6
Population development (%)	-0.1	0.4	0.7	0.7	0.3	0.6	-0.4	1.1
Availability, excluding export (tonnes)	60,773.7	45,931.0	278,153.3	28,989.0	22,776.5	10,672.7	18,631.7	6,659.7
Availability development (%)	61.0	14.8	12.4	19.4	11.2	24.4	130.4	13.8
Consumption per person (kg per capita)	1.3	0.6	0.9	0.4	1.3	0.9	1.8	0.8
Import price (USD/ kg)	6.9	7.9	4.0	8.2	8.7	8.6	8.9	12.2
Import quantity (tonnes)	24,368.0	39,666.0	171,730.0	28,989.0	16,276.5	7,987.3	938.0	3,537.3
Import development (%)	226.8	15.8	19.1	17.0	4.7	19.7	61.2	22.2
GDP (USD per capita)	30,523.9	48,195.6	62,641.0	42,491.4	52,978.4	46,556.1	23,145.7	82,838.9
Cost of cross border trade (USD)	1,400.0	1,050.0	1,390.5	1,053.0	975.0	1,400.0	925.0	1,468.0

Source: UNComtrade, FAOSTAT, World Bank

8.4.3 Wholesale prices and costs of transportation

Raspberries retail for around 20–25 USD per kilogram. Locally produced raspberries can be sold for as low as 15 USD per kilogram while organic raspberries can go for up to 33 USD per kilogram (www.cbi.eu).

2 https://www.freshplaza.com/article/9222741/overview-global-raspberry-blackberry-and-redcurrant-market/

Table 56

Raspberry wholesale prices in USD per kg for selected countries.

	min	max	average	Comments	Source
Spain	6.50	7.05	7.00	wholesale price	Fresh plaza
Germany	8.00	10.00	9.00	wholesale price	BLE.de
United States	10.00	24.00	17.00	wholesale price	Fresh plaza
United Kingdom	6.70	13.10	9.88	wholesale price	gov.uk
Netherlands	7.00	11.00	9.00	wholesale price	Fresh plaza
Belgium	7.00	11.00	9.00	wholesale price	NL price
Portugal	6.50	7.50	7.00	wholesale price	Spanish price
Switzerland	8.00	10.00	9.00	wholesale price	NL price

Raspberries are very well suited to be transported by airfreight: they have high value and low weight so this helps to keep the transportation costs per kilogram low. Sales prices are per kilogram so this would imply that the transportation costs are only a small part of the cost structure.

Table 57

Transportation costs in USD per kg from Iceland to selected countries Raspberry wholesale prices for selected countries.

Destination	Port	min	max	average
Spain	Madrid	1.00	2.00	1.50
Germany	Frankfurt	1.00	2.00	1.50
United States	New York	3.00	4.00	3.50
United Kingdom	London	1.00	2.00	1.50
Netherlands	Rotterdam	1.00	2.00	1.50
Belgium	Liege	1.00	2.00	1.50
Portugal	Porto	1.00	2.00	1.50
Switzerland	Zurich	1.00	2.00	1.50

8.4.4 Import levies

Raspberries produced in Iceland and exported to the EU are exempted from any import levy due to a preferential tariff agreed in 1994. Also for Switzerland there is a free trade agreement and as a result, raspberries are not taxed. For export to the United States a fee of 0.18 USD per kg is applied as import levy.

8.4.5 Synthesis

Production of raspberry in Iceland and shipping to the selected international markets is not profitable considering the current market prices. The only market that will provide prices that will give a positive profit margin is the United States. Some other berries are easier to transport by boat. For example, blueberries can withstand a (cooled) transportation period of more than 50 days. Currently blueberries are being shipped by boat from Chile to China. However blueberries transported by air are normally considered to be off higher quality and receiver higher prices in the market.

Table 58
Results raspberry in USD per kg.

	Calculated cost price for production	Transportation cost	Import levy	Total cost price	Average wholesale price	Margin
United States	9.25	3.50	0.18	12.93	17.00	4.07
United Kingdom	9.25	1.50		10.75	9.88	-0.87
Germany	9.25	1.50		10.75	9.00	-1.75
Netherlands	9.25	1.50		10.75	9.00	-1.75
Belgium	9.25	1.50		10.75	9.00	-1.75
Switzerland	9.25	1.50		10.75	9.00	-1.75
Spain	9.25	1.50		10.75	7.00	-3.75
Portugal	9.25	1.50		10.75	7.00	-3.75

8.5 Fresh avocado

8.5.1 Introduction

Avocados have become a standard product for European retailers. The demand for avocados is strong and still rising and more and more suppliers from new avocado countries try to enter the European market. With competition becoming more intense, occasional oversupply becomes unavoidable. In the next years, the avocado market will mature further with more focus on fruit ripening and higher standards.

8.5.2 Markets

The Netherlands is the main trade hub for avocados in Europe. You will find several major avocado importers in the Netherlands, where avocados are ripened and from where they are distributed to many European destinations. The Netherlands is responsible for half of Europe's avocado imports. But the country is also the second-largest non-producing exporter of avocados in the world. Large volumes are re-exported to Germany, France, the United Kingdom, Scandinavian countries and many others. Because of the leading role in avocado trade, the Dutch market is familiar with avocados and has a large consumer market. With a relatively small population of 17 million people, it is among the top five largest consumers in Europe. However, there are some discrepancies in trade statistics which may have altered the calculated consumption. But differences in the registered imports again confirms the leading role of the Netherlands as a trade hub for avocados. The Netherlands will remain a trade hub for avocados but over time its function may become more logistical and less commercial. Besides, a traditional wholesaler does not take many risks with importing long-distance avocados. Large fruit wholesalers, such as Staay Food Group, maintain a large international network and offer their cash and carry service point, where clients can purchase a wide variety of fruit and vegetables.

Avocado consumption in the US has steadily grown over the last several years, making it one of the most beloved fruits in the US. Industry players are diversifying Hass-producing regions, keeping traditional origins such as California, Mexico, and Chile and expanding in producing/exporting countries like Peru and Colombia, to be able to meet the growing year-round demand for the creamy fruit. Avocado per capita consumption in the US has grown at an annual growth rate of 8% during the last decade, to above 3.6kg per person per year, according to Rabobank. Despite the continuous growth in avocado availability over the last decade, prices have also consistently increased for every week of the year, which suggests the existence of a strongly expanding year-round consumer demand that is heavily reliant on imports.

Over the last decade, Mexico has been the dominant provider of avocados in the US market, followed by California, and during the last few years, shipments from Peru have sharply increased. Chile, once a relevant avocado supplier to the US market, has diversified its exports, focusing on European and Asian markets. Colombia is the newcomer in the market, with exports that will increase in the next few years.

The United Kingdom is the second-largest market for avocados, but with high standards and increasing price pressure, you must be competitive and well organised at the same time. The United Kingdom imported 111,000 tonnes of avocados. This was much more than in the previous years. Expects prices to face more pressure due to inflation, while the quality and certification standards remain one of the highest.

The German market for avocado provides a good growth perspective. Promotion of health benefits and discount offers are important drivers for a fast-rising avocado market. This makes it an interesting country for exporters. Germany is probably the country with the most growth perspective besides Italy. Germany has the largest population and is still developing its avocado market. Currently, the consumption is below 800g per capita but rising. Avocados are praised because of their health benefits and the German consumption is expected to catch up with other northwest-European markets. Affordable retail prices have contributed to higher imports.

The far East is an upcoming market for avocado and relies heavily on imports. Both supply and demand are growing stronger every year but domestic production is still in its early days. Currently China and Hong Kong import avocadoes from Mexico and Peru. However wholesale prices in China can be very low due to serious supplies coming from other producing countries that cannot find a market for their produce due to a variety of reasons. As a result, avocados are sometimes dumped on the Chinese market (no certification requirements etc). If traders are not able to sell fast, they sell for low prices due to due to limited storage possibilities and an often interrupted cold chain.

Table 59
Market selection indicators.

	NLD	HKG	USA	SVN	ESP	GBR	DEU	BEL
Population (1,000)	17,021.3	7,371.7	327,096.3	2,076.4	46,692.9	67,141.7	83,124.4	11,482.2
Population development (%)	0.3	0.7	0.7	0.2	-0.1	0.7	0.4	0.6
Availability, excluding export (tonnes)	233,018.5	21,015.3	1,169,236.7	14,053.5	212,780.0	111,806.0	87,123.7	29,475.3
Availability development (%)	26.9	115.4	12.1	434.6	11.8	30.0	29.0	37.4
Consumption per person (kg per capita)	13.7	2.9	3.6	6.8	4.6	1.7	1.0	2.6
Import price (USD/ kg)	2.4	9.3	2.7	3.2	2.3	2.7	3.5	3.2
Import quantity (tonnes)	233,018.5	21,015.3	1,014,561.3	14,053.5	121,434.3	111,806.0	87,123.7	29,475.3
Import development (%)	20.2	101.0	17.6	326.0	34.8	26.2	25.4	32.8
GDP (USD per capita)	52,978.4	48,717.3	62,641.0	26,234.0	30,523.9	42,491.4	48,195.6	46,556.1
Cost of cross border trade (USD)	975.0	640.3	1,390.5	830.0	1,400.0	1,053.0	1,050.0	1,400.0

Source: UNComtrade, FAOSTAT, World Bank

8.5.3 Wholesale prices and costs of transportation

Trade prices for avocados fluctuate mostly depending on the available volume. The summer prices are generally low due to the higher offer, especially from Peru. Other influences that determine prices are quality, size and variety. The highest prices are generated by Class I Hass avocados around size 18.
Average wholesale prices are approximately 9 to 11.6 USD per 4 kg box. Peak prices go up to 16.3 USD per box for excellent quality and when supply is scarce, but bottom prices of 4.7 or 5.8 USD wholesale have also been recorded at times of oversupply. It can be stated that the EU price is reflected by the price traded on the Dutch fresh market. However, this does not include Spain, since they have their domestic production of avocados which has a different price setting. See also Annex 1 for seasonality of the avocado prices in the United States, the Netherlands and Spain.

Avocado trade prices are likely to develop in an upward trend over the next years, but peaks and lows will remain present due to an uneven growth rate of supply and demand.

Table 60

Avocado wholesale prices for selected countries in USD per kg.

Indicator	min	max	average	Comments	Source
The Netherlands	2.0	4.7	3.4	Wholesale price	USDA
China, Hong Kong SAR			4.0	Wholesale price	Freshplaza
United States	2.1	7.0	4.6	Wholesale price	USDA
Slovenia	2.0	4.7	3.4	Wholesale price	USDA
Spain	3.0	3.6	3.3	Wholesale price	USDA
United Kingdom	2.0	4.7	3.4	Wholesale price	USDA
Germany	2.0	4.7	3.4	Wholesale price	USDA
Belgium	2.0	4.7	3.4	Wholesale price	USDA

Source: EUROSTAT, USDA

Avocados are often transported under controlled conditions in a cooled sea container. A single 40 ft container can contain 5,280 4 kg boxes. This means that a total volume of 21,120 kg of avocado is being shipped at once. See the table below for an overview of the different freight rates.

Table 61

Transportation costs in USD from Iceland to selected countries.

Destination	Port	min	max	average	Container load (kg)	Price per kg
To the Netherlands	Rotterdam	707	760	734	21,120	0.03
To China	Shanghai	5,298	5,856	5,577	21,120	0.26
To the United States	New York	5,736	6,340	6,038	21,120	0.29
To Slovenia	Rotterdam	707	760	734	21,120	0.03
	From Rotterdam to Ljubljana by truck	613	678	646	21,120	0.03
	Total	1,320	1,438	1,379		0.07
To Spain	Rotterdam	707	760	734	21,120	0.03
	From Rotterdam to Santander by ship	1,639	1,812	1,726	21,120	0.08
	Total	2,346	2,572	2,459		0.12
To the United Kingdom	Hull	733	810	772	21,120	0.20
To Germany	Hamburg	713	788	751	21,120	0.31
To Belgium	Antwerp	719	795	757	21,120	0.51

Source: World Freight Rates

8.5.4 Import levies

Avocado produced in Iceland and exported to the EU are exempted from any import levy due to a preferential tariff agreed in 1994. Also for Switzerland there is a free trade agreement and as a result avocados are not taxed. For export to the United States a fee of 0.112 USD per kg is applied as import levy.

8.5.5 Synthesis

Production of avocados in Iceland and shipping to the selected international markets is not profitable considering the current market prices. For the calculated cost price for production, we used the cost price for greenhouse production in Akureyri which is the location where production cost per kg is the lowest.

Table 62
Results avocado and total prices in USD per kg.

	Calculated cost price for production	Transportation cost	Import levy	Total cost price	Average wholesale price	Margin
United States	43.12	0.29	0.11	43.52	4.55	-38.97
China, Hong Kong SAR	43.12	0.26		43.38	4.00	-39.38
The Netherlands	43.12	0.03		43.15	3.35	-39.80
Slovenia	43.12	0.03		43.15	3.35	-39.80
Germany	43.12	0.03		43.15	3.35	-39.80
United Kingdom	43.12	0.07		43.19	3.35	-39.84
Spain	43.12	0.03		43.15	3.30	-39.85
Belgium	43.12	0.08		43.20	3.35	-39.85

8.6 Tomato

8.6.1 Introduction

Heated tomato cultivation is on the move worldwide. Consumers have discovered the wealth of shapes, flavours and colours. They also experiment with new applications. They expect a recognizable product, which is high in taste, all year round. The fresh tomato supply has changed radically in the past twenty-five years. Once there were mainly beef tomatoes, loose round tomatoes and - as a prelude to what was to come - cherry tomatoes on the shelves. The tomato assortment has been expanded with cocktail tomatoes, plum tomatoes, cluster and snack tomatoes in all shapes, sizes and colours. And that, in turn, has consequences for the strategy and cultivation methods of producers. Investing in growth, geographical spread and assimilation lighting have created companies that can serve their customers all year round with fruits of a consistent, very high quality.

Tomatoes are among the top of the list of most consumed vegetables worldwide. The most recent FAOSTAT figures (2018) indicate that 182.3 million tonnes of tomatoes are produced worldwide. As a result, production was almost 30% higher than ten years earlier. Almost 5 million hectares are planted with tomatoes all over the world. An average of 3.7 kilos per square meter is harvested from that area. The largest producers are China and India, although the yield in India is low at less than 2.5 kilos per square meter. This is in contrast to the yields that growers in the United States (9.0 kg per m^2), Spain (8.6 kg per m^2) and Morocco (8.1 kg per m^2). With an average of 50.7 kg per m^2, the Dutch tomato producer yield the best results.

8.6.2 Markets

For tomato, we have identified a short list of the 8 most promising markets. Slovenia is a key market since tomato availability has increased a lot in the last 10 years. Also the Netherlands is a key market, due to its large imported volume mainly for the (re)export. Other countries are the United States, Spain, Italy, Israel and France. All countries with serious domestic tomato consumption, production and import. Also, the United Arab Emirates is an interesting market for its increase in tomato import. However, the United Arab Emirates is seriously envisioning investing in its domestic production of vegetables to reduce dependency on imports. The table below gives an overview of some of the key market indicators.

Table 63
Market selection indicators.

	SVN	NLD	USA	ESP	ITA	ARE	ISR	FRA
Population (1,000)	2,076	17,021	327,096	46,647	60,627	9,487	8,243	64,842
Population development (%)	0.2	0.3	0.7	-0.2	0.3	0.8	1.7	0.4
Availability, excluding export (tonnes)	345,274	1,129,307	14,045,765	5,371,561	6,219,538	221,094	397,037	1,299,480
Availability development (%)	281.8	1.5	-1.7	3.4	-0.4	2.3	-1.6	2.1
Import price (USD/ kg)	0.4	0.7	0.9	0.4	0.9	2.9	1.0	0.9
Import quantity (tonnes)	336,750	224,307	1,835,415	173,057	135,691	159,080	17,617	483,444
Import development (%)	273.1	-0.2	2.6	3.7	1.8	-0.1	426.5	-1.0
GDP (USD per capita)	26,234	52,978	62,641	30,524	34,318	43,005	41,614	41,463
Cost of cross border trade (USD)	830.0	975.0	1,390.5	1,400.0	1,145.0	962.3	699.0	1,445.0

Source: UNComtrade, FAOSTAT, World Bank

8.6.3 Wholesale prices and costs of transportation

Useable wholesale prices for tomato only were found for the German market. German wholesale prices give a good indication for the rest of the Northern European market. However price in the Southern part (Spain, Italy, France) are normally much lower due to the different production systems mainly without heating and under simple basic plastic structures.

The BLE monitors the fruit and vegetable markets in Germany to collect data for the European Union and the Federal Ministry of Food and Agriculture (BMEL). The general market situation is determined and summarized in a weekly market and price report. Based on available data for loose tomatoes in the whole year of 2018, the average wholesale price is around 1.32 USD per kg. For the United Arab Emirates (UAE) we could not retrieve public information, so we relayed on expert information from WUR researchers that are working in the region. Prices of around 2.7 AED per kg of tomato are common for locally produced tomato. However imported tomatoes of higher quality can fetch better prices.

Table 64

Tomato wholesale prices in USD per kg of selected countries.

	min	max	average	
Slovenia	0.64	2.00	1.32	Based on German Wholesale prices www.ble.de
Netherlands	0.64	2.00	1.32	Based on German Wholesale prices www.ble.de
United States	1.50	3.85	2.68	2019 prices based on the USDA prices for NY wholesale market
Spain	0.20	1.50	0.85	https://www.mercasa.es/
Italy	0.20	1.50	0.85	Based on Wholesale prices in Spain
United Arab Emirates	0.60	0.80	0.70	Expert information, based on local prices.
Israel	0.64	2.00	1.32	Based on German Wholesale prices www.ble.de
France	0.20	1.50	0.85	Based on Wholesale prices in Spain

Due to limited shelf life it is best to transport tomato by air freight. Costs indications could not be found online or by contacting parties like Icelandair or other service providers. Therefore we used common industry standards as a proxy for the costs of transport. For destination within Europe, a price between 1 USD per kg and 2 USD is accurate. Destination further away can go up to 4 USD. However, air freight prices tend to fluctuate heavily depending on the price of fuel.

Table 65

Transportation costs in USD per kg from Iceland to selected countries.

Destination	min	max	average
Slovenia	1.00	2.00	1.50
Netherlands	1.00	2.00	1.50
United States	3.00	4.00	3.50
Spain	1.00	2.00	1.50
Italy	1.00	2.00	1.50
United Arab Emirates	3.00	4.00	3.50
Israel	1.00	2.00	1.50
France	1.00	2.00	1.50

Source: Estimates by WUR

8.6.4 Import levies

Tomato produced in Iceland and exported to the EU are exempted from any import levy due to a preferential tariff agreed in 1994. Also for the UAE there is a free trade agreement and as a result tomatoes are not taxed. For export to the United States a fee of 0.04 USD per kg is applied as import levy and for Israel this 0.30 USD per kg.

8.6.5 Synthesis

Production of (loose) tomato in Iceland and shipping to the selected international markets is not profitable considering the current market prices. For the calculated cost price for production, we used the cost price for greenhouse production in Akureyri which is the location where production cost per kg is the lowest.

Table 66
Results tomato in USD per kg.

	Calculated cost price for production	Transportation cost	Import levy	Total cost price	Average wholesale price	Margin
Slovenia	1.19	1.50		2.69	1.32	-1.37
Netherlands	1.19	1.50		2.69	1.32	-1.37
Israel	1.19	1.50	0.30	2.99	1.32	-1.67
Spain	1.19	1.50		2.69	0.85	-1.84
Italy	1.19	1.50		2.69	0.85	-1.84
France	1.19	1.50		2.69	0.85	-1.84
United States	1.19	3.50	0.04	4.73	2.68	-2.05
United Arab Emirates	1.19	3.50		4.69	0.70	-3.79

8.7 Lettuce

8.7.1 Introduction

The convenience trend means that most lettuce is nowadays sold cut and pre-packaged. Lettuce mixes with various leaf colours are also a trend in foodservice. Therefore, there are plenty of developments in lettuce that immediately falls apart as loose leaves. There is already plenty of variation in leaf shape and colour, in firmness loose-leaf varieties are maturing.

Lettuce varieties that growers can harvest at the stage between baby leaf and adult crop are becoming popular. One of the major advantages is that cutting plants have less waste and thus achieve maximum yield.

According to the figures, millions of tonnes of lettuce are grown worldwide on an annual basis. Most of that production can be found in China, accounting for 6.3 million tonnes. Other countries that are among the top largest producers include Belgium, France, India, Italy, Japan, Mexico, Spain and the United States.

8.7.2 Markets

For lettuce we have identified a short list of the 8 most promising markets for the fresh produce from Iceland, see the table below.

The total availability of lettuce on yearly basis in Slovenia is 46,849 tonnes and it had a yearly growth rate of 28.5% (based on 10 years). The availability per person is 22.6 kg. Slovenia yearly imports 27,553 tonnes of lettuce and it had had a yearly growth rate of 76.7% (based on 10 years).

The annual total availability of lettuce in the United States is 4.5 million tonnes and it had a yearly growth rate of - 1.51% (based on 10 years). The consumption per person is 13.7 kg. The United States yearly imports 191,174 tonnes of lettuce and it had a yearly growth rate of 34% (based on 10 years).

Total lettuce availability in Italy on yearly basis is 783,942 tonnes and it had a yearly growth rate of 0% (based on 10 years). The consumption per person is 12.9 kg. Italy yearly imports 37,310 tonnes of lettuce and it had a yearly growth rate of 5.6% (based on 10 years).

The annual total availability of lettuce in the Netherlands is 167,419 tonnes and it had a yearly growth rate of 1.8% (based on 10 years). The consumption per person is 9.8 kg. The Netherlands yearly imports 54,669 tonnes of lettuce and it had had a yearly growth rate of -2.3% (based on 10 years).

Denmark is a country with a population of 5,752 inhabitants with an average growth rate of 0.4% over the last 10 years. GDP per capita is 60,595 USD. Their total consumption of lettuce on yearly basis is 32,783 tonnes and it had a yearly growth rate of 4.4% (based on 10 years). The consumption per person is 5.7 kg. Denmark yearly imports 13,182 tonnes of lettuce and it had a yearly growth rate of -0.9 % (based on 10 years).

Germany is one of the most important markets for lettuce since the Germans eat a lot of salads. The country with a population of 82.7 million inhabitants with an average growth rate of 0.4% over the last 10 years. It has a GDP per capita is 48,195 USD. Their total availability of lettuce on yearly basis is 502,920 tonnes and it had a yearly growth rate of -0.1% (based on 10 years). Germany yearly imports 159,461 tonnes of lettuce and it had a yearly growth rate of -1.6% (based on 10 years).

Hong Kong has a population of 7.4 million inhabitants with an average growth rate of 0.9% over the last 10 years. The GDP per capita is 48,717 USD. Their total availability of lettuce on yearly basis is 20,117 tonnes and on an annual base there is hardly any growth in consumption of lettuce. The consumption per person is 2.7 kg. Hong Kong yearly imports 15,407 tonnes of lettuce and it had a yearly growth rate of 5.6 % (based on 10 years).

Sweden is a country with a population of almost 10 million inhabitants with an average growth rate of 0.8% over the last 10 years. Its GDP per capita is 54,112 USD. The total availability of lettuce on yearly basis is 39,115 tonnes and it had a yearly growth rate of 2.2% (based on 10 years). Sweden yearly imports 8,485 tonnes of lettuce and it had a yearly growth rate of 1.2% (based on 10 years average).

Table 67 *Market selection indicators*

	SVN	USA	ITA	NLD	DNK	DEU	HKG	SWE
Population (1,000)	2,076.4	327,096.3	60,627.3	17,021.3	5,752.1	82,658.4	7,371.7	9,971.6
Population development (%)	0.2	0.7	-0.0	0.3	0.4	0.4	0.9	0.8
Availability, excluding export (tonnes)	46,849.0	4,480,205.3	783,941.7	167,419.5	32,783.3	502,920.0	20,117.3	39,115.7
Availability development (%)	28.5	1.5	-	1.8	4.4	-0.1	-	2.2
Import price (USD/ kg)	0.9	0.7	0.8	1.9	1.1	1.5	4.8	3.0
Import quantity (tonnes)	27,553.5	191,174.7	37,310.0	54,669.5	13,181.7	159,461.5	15,407.0	8,485.7
Import development (%)	76.7	34.0	5.6	-2.3	-0.9	-1.6	5.6	1.2
GDP (USD per capita)	26,234.0	62,641.0	34,318.4	52,978.4	60,595.6	48,195.6	48,717.3	54,112.0
Cost of cross border trade (USD)	830.0	1,390.5	1,145.0	975.0	745.0	1,050.0	640.3	735.0

Source: UNComtrade, FAOSTAT, World Bank

8.7.3 Wholesale prices and cost of transportation

Pricing of lettuce is by the head. This is very different compared to other vegetables where there is a price kilogram. Wholesale prices for lettuce only were found for the German and the market in the United States. As stated before, the German wholesale prices give a good indication for the rest of the European market.

Based on available data for lettuce in the year 2019, the average wholesale price is estimated at 0.80 USD a unit. The minimum price is 0.56 USD a head and the maximum price is 1.54 USD per head. In the United States the lettuce prices are a higher and a single head of lettuce can go as high as 3 USD per unit (see the table below).

Table 68

Lettuce wholesale prices in USD per head of selected countries

Indicator	min	max	average	Comments / *Source*
Slovenia	0.46	1.55	1.01	*Based on German Wholesale prices www.ble.de*
United States	2.00	3.00	2.50	Lettuce Romaine, New York Terminal *USDA*
Italy	0.30	2.18	1.40	Estimation based on 50% of the retail price for 1 head of 1.25 USD as mentioned in the Numbeo cost of living data base *www.numbeo.com*
Netherlands	0.46	1.55	1.01	*Based on German Wholesale prices www.ble.de*
Denmark	0.46	1.55	1.01	*Based on German Wholesale prices www.ble.de*
Germany	0.46	1.55	1.01	*www.ble.de*
Hong Kong	0.32	0.46	0.40	Estimation based on 50% of the retail price for 1 head of 1.25 USD as mentioned in the Numbeo cost of living data base *www.numbeo.com*
Sweden	0.46	1.55	1.01	*Based on German Wholesale prices www.ble.de*

Due to limited shelf life, it is best to transport lettuce by air freight. As stated before, clear costs indications could not be found online or by contacting parties like Icelandair or other service providers. Therefore we used common industry standards as a proxy for the costs of transport. For destinations within Europe, a price between 1 USD per kg and 2 USD is accurate. Destination further away can go up to 4 USD. However, air freight prices tend to fluctuate heavily depending on the price of fuel. The weight of a single head is estimated between 220 and 250 grams. This implies that a single kg will contain 4 heads.

Table 69

Transportation in USD per kg costs from Iceland to selected countries.

Destination	min	max	average
Slovenia	1.00	2.00	1.50
United States	3.00	4.00	3.50
Italy	1.00	2.00	1.50
The Netherlands	1.00	2.00	1.50
Denmark	1.00	2.00	1.50
Germany	1.00	2.00	1.50
Hong Kong	3.00	4.00	3.50
Sweden	1.00	2.00	1.50

Source: Estimates by WUR

8.7.4 Import levies

Lettuce produced in Iceland and exported to the EU are exempted from any import levy due to a preferential tariff agreed in 1994. Also for the Hong Kong lettuce is not taxed. For export to the United States a fee of 0.4 USD per kg (or 0.10 per head) is applied as import levy.

8.7.5 Synthesis

Lettuce production in Iceland and shipping towards the selected international markets is profitable for the studied countries. For the calculated cost price for production, we used the cost price for greenhouse production in Akureyri which is the location where production cost per kg is the lowest.

Table 70

Results lettuce in USD per head

	Calculated cost price for production	Transportation cost	Import levy	Total cost price	Average wholesale price	Margin
United States	0.35	0.88	0.10	1.33	2.50	1.17
Italy	0.35	0.38		0.73	1.40	0.67
Slovenia	0.35	0.38		0.73	1.01	0.28
The Netherlands	0.35	0.38		0.73	1.01	0.28
Denmark	0.35	0.38		0.73	1.01	0.28
Germany	0.35	0.38		0.73	1.01	0.28
Sweden	0.35	0.38		0.73	1.01	0.28
Hong Kong	0.35	0.88		1.23	0.40	-0.83

8.8 Sweet pepper

8.8.1 Introduction

Sweet pepper or bell peppers trade mainly takes place within the EU and North America. According to the trade statistics, only 3 countries dominate exports: Spain, Mexico and the Netherlands. In total, they represent almost two-thirds of the total world trade.

We observe a shift in supply in Europe: Growers in northern Europe close the season later (in October), while the first production from southern Europe is coming earlier. In October, produce from Spain is already being harvest.

Sweet peppers come in different colours: red, green, orange and yellow. Red peppers are by far the most popular. Peppers are mainly eaten as part of a salad, along with tomato, cucumber, onion and lettuce. Besides, pepper is eaten as part of a hot meal. There are small differences per country. In Germany, sweet peppers are eaten more often as part of a salad, while in the Netherlands and the United Kingdom sweet peppers are more often part of a hot meal.

8.8.2 Markets

For sweet peppers we have identified a shortlist of the 8 most promising markets for the fresh produce from Iceland:

The annual capsicum availability in Slovenia is 265,515 tonnes and it had a yearly growth rate of 464% (based on 10 years). Slovenia yearly imports 265,515 tonnes of capsicum and it had a yearly growth rate of 348% (based on 10 years).

The annual capsicum availability in Germany is 403,234 tonnes and it had a yearly growth rate of 2.5% (based on 10 years). The consumption of capsicum is 4.9 kg per person. Germany yearly imports 403,234 tonnes of capsicum and it had a yearly growth rate of 1.9% (based on 10 years).

The United Kingdom has a population of 67 million inhabitants with an average growth rate of 0.7% over the last 10 years. GDP per capita is 42,491 USD. Their total consumption of capsicum on yearly basis is 234,689 tonnes and it had a yearly growth rate of 7.5% (based on 10 years). They yearly imports 234,689 tonnes of capsicum and it had a yearly growth rate of 6.5% (based on 10 years).

The total consumption of capsicum in the United States is 1.1 million tonnes and it had a yearly growth rate of 5.8% (based on 10 years). Yearly imports accounts for 1,141,329 tonnes of capsicum and it had a yearly growth rate of 5.1% (based on a 10 years average).

The United Arab Emirates has a total consumption of capsicum on yearly basis is 47,302 tonnes and it had a yearly growth rate of 4.6% (based on 10 years). The United Arab Emirates yearly imports 47,302 tonnes of capsicum and it had a yearly growth rate of 2.3% (based on 10 years). The UAE imports serious volumes but is also increasing local production.

Belgium has a population of 11.5 million inhabitants with an average growth rate of 0.6% over the last 10 years. GDP per capita is 46,556 USD. Their total consumption of capsicum on yearly basis is 52,369 tonnes and it had a yearly growth rate of 8.8% (based on 10 years). Belgium yearly imports 52,369 tonnes of capsicum and it had a yearly growth rate of 7.7% (based on 10 years).

The Netherlands yearly imports 110,872 tonnes of capsicum and it had a yearly growth rate of -1.5 % (based on 10 years). The total national availability of capsicum on yearly basis in the Netherlands is 110,872 tonnes.

Norway has a population of 5.3 million inhabitants with an average growth rate of 1.2% over the last 10 years. GDP per capita is 81,807 USD. Their total consumption of capsicum on yearly basis is 19,946 tonnes and it had a yearly growth rate of 4.4% (based on 10 years). Norway almost imports all capsicum and this is growing with a rate of 3.3% (based on 10 years).

Table 71
Market selection indicators.

ISO3	SVN	DEU	GBR	USA	UAE	BEL	NLD	NOR
Population (1,000)	2,076.4	82,658.4	67,141.7	327,096.3	9,487.2	11,482.2	17,021.3	5,296.3
Population development (%)	0.2	0.4	0.7	0.7	0.8	0.6	0.3	1.2
Availability, excluding export (tonnes)	265,515.5	403,234.5	234,689.3	1,141,329.7	47,302.5	52,369.0	110,872.0	19,946.0
Availability development (%)	463.9	2.5	7.5	5.8	4.6	8.8	-2.0	4.4
Import price (USD/ kg)	1.0	2.2	2.1	4.6	3.4	1.6	1.9	2.9
Import quantity (tonnes)	265,515.5	403,234.5	234,689.3	1,141,329.7	47,302.5	52,369.0	110,872.0	19,946.0
Import development (%)	347.9	1.9	6.5	5.1	2.3	7.7	-1.5	3.3
GDP (USD per capita)	26,234.0	48,195.6	42,491.4	62,641.0	43,004.9	46,556.1	52,978.4	81,807.2
Cost of cross border trade (USD)	830.0	1,050.0	1,053.0	1,390.5	962.3	1,400.0	975.0	1,142.0

Source: UNComtrade, FAOSTAT, World Bank

8.8.3 Wholesale prices and costs of transportation

As stated before for other crops like tomato and lettuce, the German wholesale prices give a good indication for the rest of the European market. The German Federal Office for Agriculture and Food (BBE) monitors the fruit and vegetable markets in Germany. Based on available data for capsicum red (origin all countries) in the whole year of 2019, the average wholesale price is 2.20 USD per kilogram. The minimum price is 1.68 USD per kilogram and the maximum price is 3.3 USD per kilogram.

For the United States there is a lot of price information published on the website of USADA for each city wholesale market. Prices are differentiated by the commodities' growing origin, variety, size, package and grade. For example, sweet peppers on the New York terminal vary between 20 and 40 USD per 5kg box.

Table 72
Capsicum wholesale prices for selected countries, in USD per kg.

Indicator	min	max	average	Comments	
Slovenia	1.42	3.57	2.20	All colours	Based on German Wholesale prices www.ble.de
Germany	1.42	3.57	2.20	The average for red, green and yellow sweet peppers	www.ble.de
United Kingdom	1.42	3.57	2.20	All colours	Based on German Wholesale prices www.ble.de
United States	4.00	8.00	6.00	New York Terminal market	USDA
United Arab Emirates	1.30	1.90	0.80	All colours	Expert estimation
Belgium	1.42	3.57	2.20	All colours	Based on German Wholesale prices www.ble.de
Netherlands	1.42	3.57	2.20	All colours	Based on German Wholesale prices www.ble.de
Norway	1.42	3.57	2.20	All colours	Based on German Wholesale prices www.ble.de

Due to limited shelf life, it is best to transport tomato by air freight. As stated before, clear costs indications could not be found online or by contacting parties like Icelandair or other service providers. Therefore we used common industry standards as a proxy for the costs of transport. For destination within Europe, a price between 1 USD per kg and 2 USD seems accurate. Destination further away can go up to 4 USD per kilogram. However, air freight prices tend to fluctuate heavily depending on the price of fuel.

Table 73
Transportation costs in USD per kg from Iceland to selected countries (air freight).

Destination	min	max	average
Slovenia	1.00	2.00	1.50
Germany	1.00	2.00	1.50
United Kingdom	1.00	2.00	1.50
United States	3.00	4.00	3.50
United Arab Emirates	2.00	3.00	2.50
Belgium	1.00	2.00	1.50
Netherlands	1.00	2.00	1.50
Norway	1.00	2.00	1.50

8.8.4 Import levies

Sweet peppers produced in Iceland and exported to the EU are exempted from any import levy due to a preferential tariff agreed in 1994. Also export to the UAE is duty free. For export to the USA a fee of 0.047 USD per kg is applied as an import levy.

8.8.5 Synthesis

In most countries, sweet peppers are in high demand and are often locally produced. Some countries dominate the international trade of sweet peppers and can produce at competitive on conditions. The Netherlands is very dominant and produces in high tech greenhouses realizing high yields per square meters contributing to a low costs price. Spain is another producers but is producing good volume with only low tech greenhouse but is still able to remain competitive and making benefit of a market window that the Dutch are in 'low' season. Dutch fresh produce traders are also able to sell sweet peppers in the faraway market like Japan since freight costs are relatively low due to the low weight of a single sweet pepper. At the high end retail market sweet peppers are sold per unit and many units can fit in a single kg. For the calculated cost price for production, we used the cost price for greenhouse production in Akureyri which is the location where production cost per kg is the lowest.

Table 74
Results sweet peppers in USD per kg.

	Calculated cost price for production	Transportation cost	Import levy	Total cost price	Average wholesale price per kg	Margin
USA	3.20	3.50	0.05	6.75	6.00	-0.75
Slovenia	3.20	1.50		4.70	2.20	-2.50
Germany	3.20	1.50		4.70	2.20	-2.50
United Kingdom	3.20	1.50		4.70	2.20	-2.50
Belgium	3.20	1.50		4.70	2.20	-2.50
Netherlands	3.20	1.50		4.70	2.20	-2.50
Norway	3.20	1.50		4.70	2.20	-2.50
United Arab Emirates	3.20	2.50		5.70	0.80	-4.90

8.9 Wheat

Europe is a large importer of grains, pulses and oilseeds. They are typically imported as high-volume bulk products to be processed into animal feed. For the consumer market, they are used as a staple food, or as high-value ingredients for a wide range of food products. However, only in wheat and barley, Europe has a large surplus production.

Market prices in various producing countries of wheat average 270 USD per tonne. Some countries have very high wheat prices, like countries in the Middle East, where consumption is high and production is limited. Related to the calculated cost price of 600 USD per tonne, exporting wheat from Iceland is not a profitable business case.

Table 75

Average global farm gate price for wheat average (n=70) and selected countries with higher wheat price in USD per tonne (FAOSTAT).

	2017	2018
Average price for wheat (n70)	283.3	272.3
Oman	929.8	929.8
Kuwait	824.1	827.9
Chad	487.9	637.0
Jordan	608.2	553.9
Rwanda	631.7	504.4
Peru	496.9	488.7
Switzerland	480.3	465.3

9 Conclusions

- We have studied the potentail of giga scale greenhouse and indoor factory production of food crops on iceland for as well domestic as diverse export markets.
- We can conclude that there is room for feasible production in large high tech greenhouse facilities to satisfy the demand of the domestic market for most products studied, except for cheap commodities (rice, potato, wheat).
- Greenhouse production should be preferred to indoor factory production. In the case of indoor farms, only lettuce ensures a profit. We might assume that perhaps also other leafy greens and/or aromatics and herbs might be suitable.
- To export fruits or staple crops like wheat large volumes are required to fill containers.
- To export fruits serious additional investments are required in packhouses
- The analysis also indicates that there are no major differences in operating giga farms between the South and the North cost of Iceland Since in terms of greenhouse crop production desing perspective the outdoor climate is relatively comparable, except that there is more snowfall in the North. Necessary equipment necessary for control of crop growing conditions is comparable.
- The combined analysis of cost/benefit and market indicates that there are clearly three groups of crop products:
  - One group, composed of highly productive mineral and vitamin-rich crops with a large water content (lettuce, tomato, sweet pepper), which are close to profit. However, the main bottleneck in mostly all analysed combinations are the high transport prices by airplane due to their short post-harvest life. The only product in this group for which complete indoor factory production would be a feasible option are lettuces. A rational boost of production and decrease of resource potentially obtained by the use of AI could bring these products closer to benefit, but high transport cost would still remain a burden to build feasible business cases.
  - Another group, represented by caloric and protein-rich products with low productivity per unit area, which have a large dry matter content (rice, potato, banana, avocado and wheat), for which production in protected environment is simply not profitable, given their low productivity per unit area and the cheap price in the destination markets, given the large supply of these products from open field cultivation worldwide and possibilitiesfor long term storage. There is also steep competition for this product of a few dominant producers (for example in banana trade). The use of AI or an extremely low price of operational costs are still not sufficient to bring these crops close enough to profit.
  - A final group represented by products for which combinations of nearby market and high destination value could lead to clear profit (i.e. raspberries in the USA and to a lesser extent, in the UK). However, profit margin is still relatively low (about 12%) and this far below the industry standard. In this group, again, lowering transport costs would allow for more positive combinations. The use of AI or a decrease in the price of the major operational costs (i.e. electricity) would help in improving the cost/benefit balance.
- The methodology explained and used in this study is suitable to be used for the analysis of the potential of proteced cultivation in other regions of the world.

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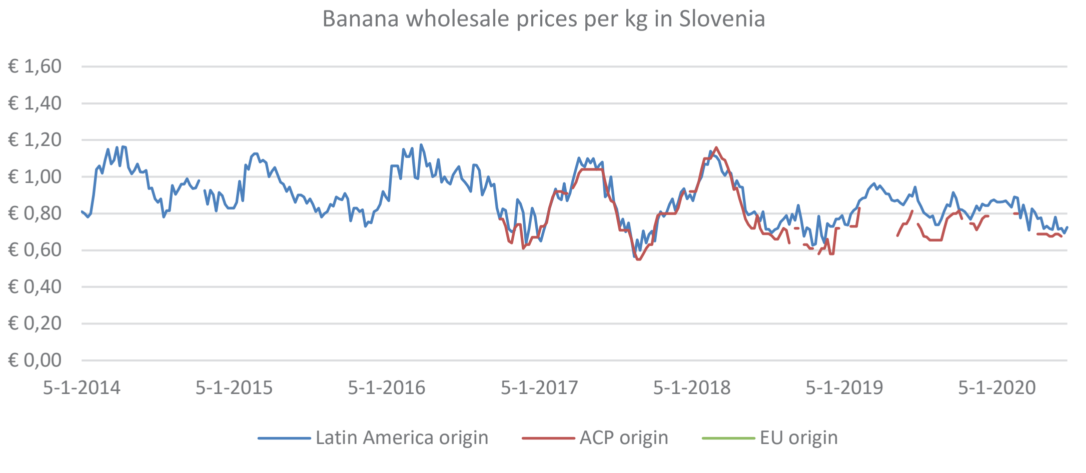
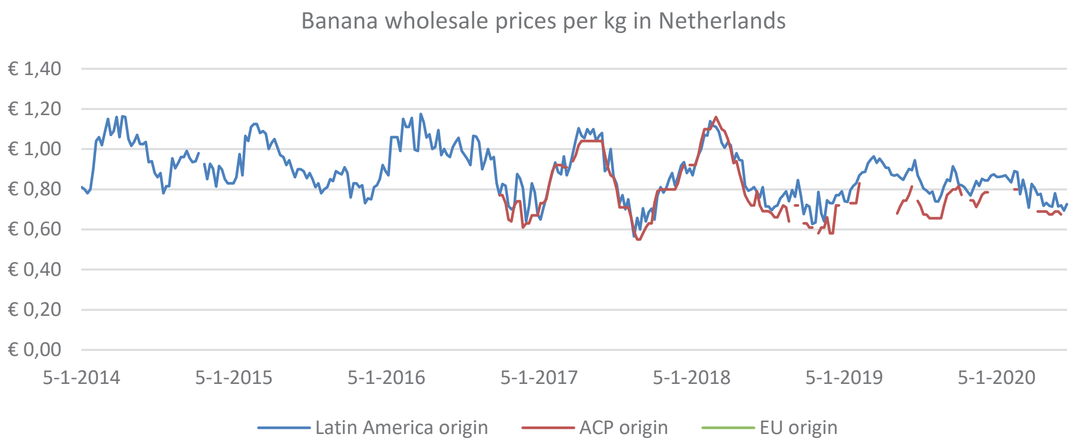
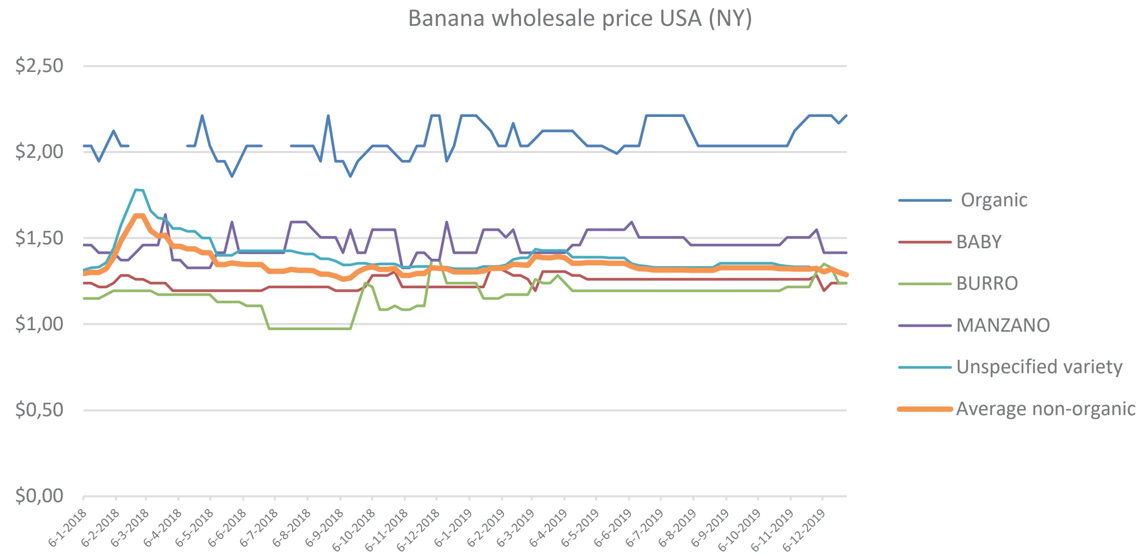
Annex 1 Wholesale prices banana



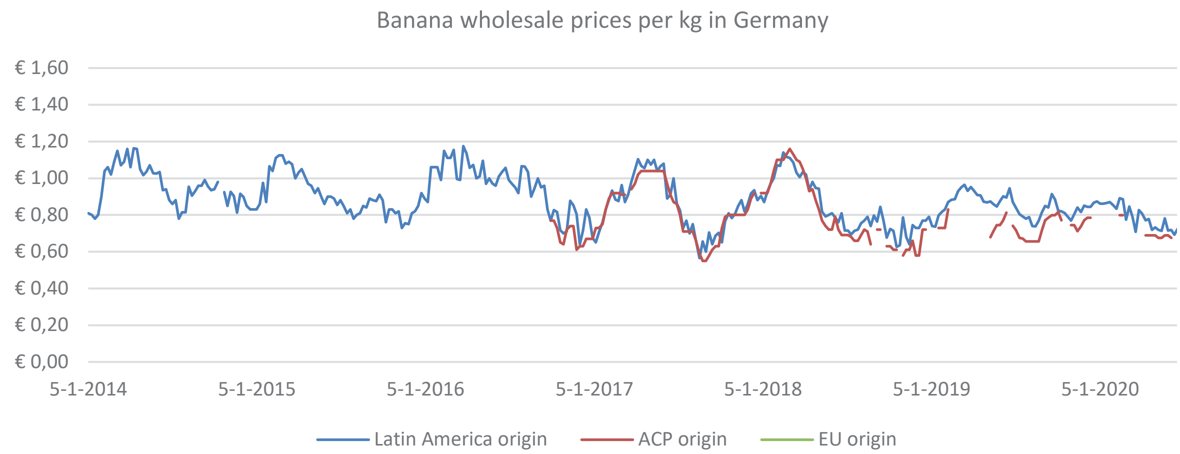
Weekly wholesale prices in euro per kg of bananas (all varieties) in Slovenia, by region of origin: Latin America, Africa, Caribbean and Pacific (ACP), and EU. Source: European Commission. Statistics on bananas production, prices and trade.



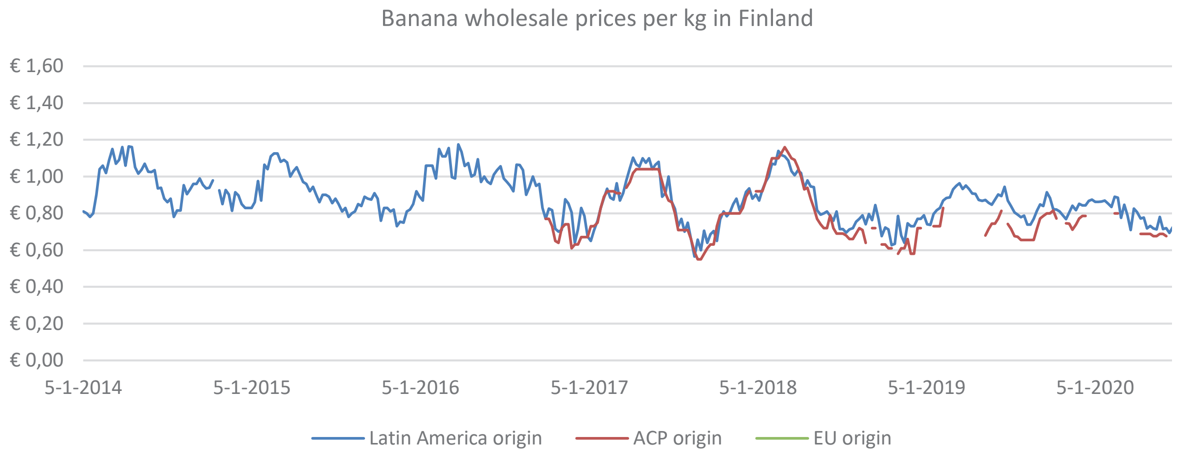
Weekly wholesale prices in euro per kg of bananas (all varieties) in the Netherlands, by region of origin: Latin America, Africa, Caribbean and Pacific (ACP), and EU. Source: European Commission. Statistics on bananas production, prices and trade.



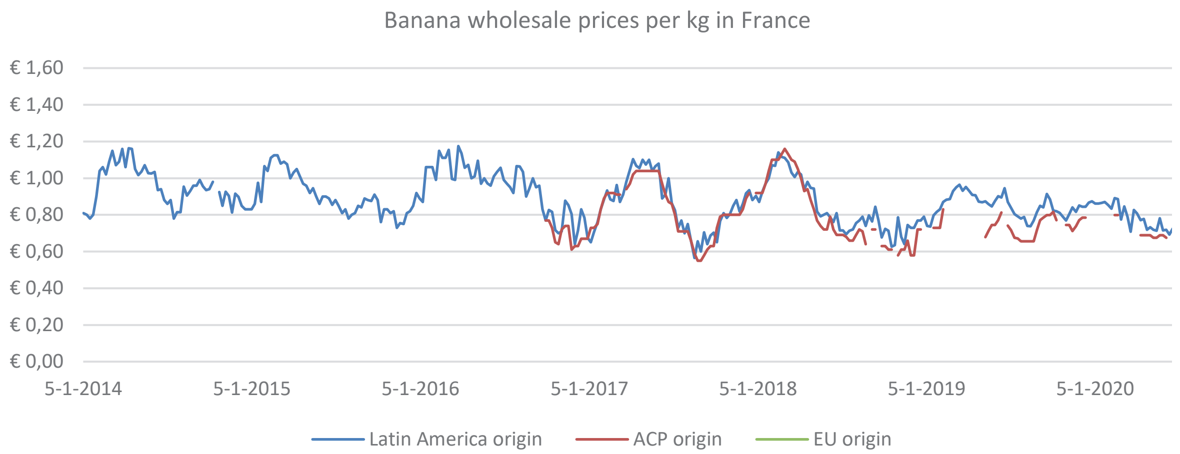
Weekly average wholesale prices (middle price) in US dollar per kg of bananas, by variety, 40 lb cartons mostly. New York terminal market. From January 2018 to December 2019 Source: USDA Agricultural Market Service Terminal Market Reports..



Weekly wholesale prices in euro per kg of bananas (all varieties) in Germany, by region of origin: Latin America, Africa, Caribbean and Pacific (ACP), and EU. Source: European Commission. Statistics on bananas production, prices and trade.

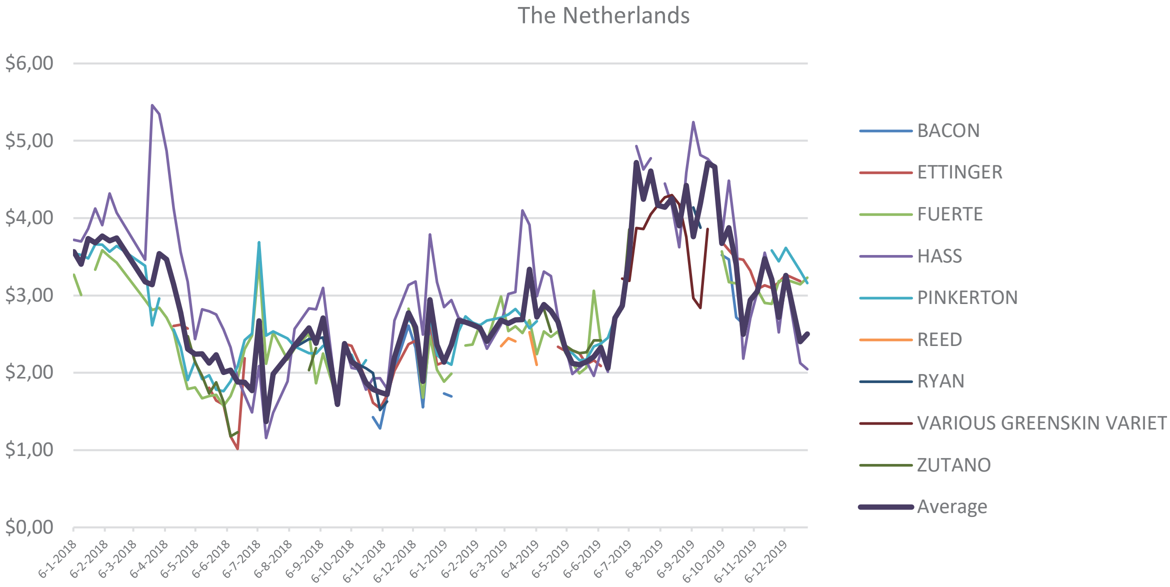


Weekly wholesale prices in euro per kg of bananas (all varieties) in Finland, by region of origin: Latin America, Africa, Caribbean and Pacific (ACP), and EU. Source: European Commission. Statistics on bananas production, prices and trade.



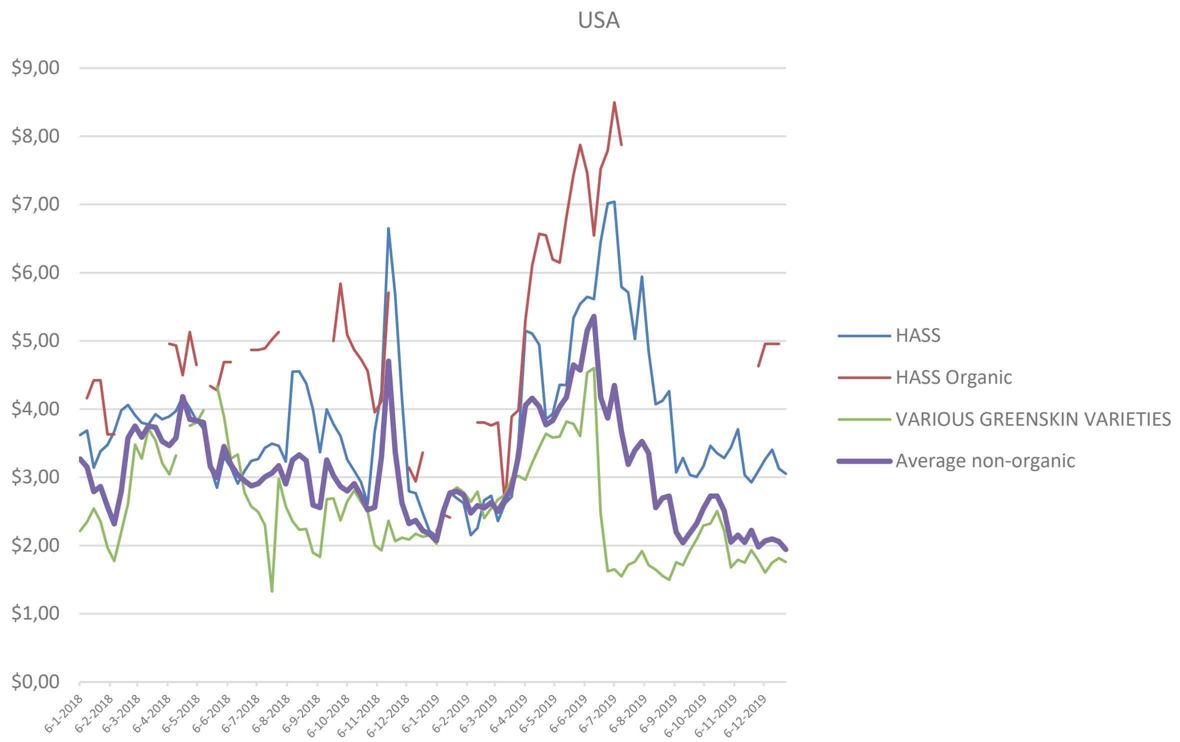
Weekly wholesale prices in euro per kg of bananas (all varieties) in Finland, by region of origin: Latin America, Africa, Caribbean and Pacific (ACP), and EU. Source: European Commission. Statistics on bananas production, prices and trade.

Annex 2 Wholesale price avocado

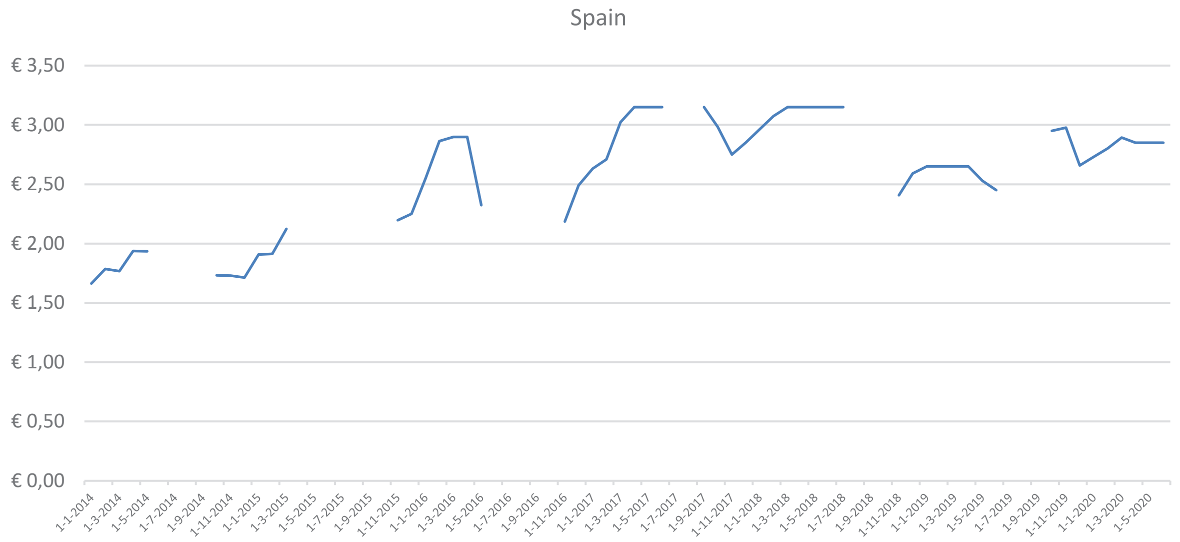


Weekly average wholesale prices (middle price) in US dollar per kg of avocados in the Netherlands, by variety, 4 kg containers mostly. Rotterdam terminal market. From January 2018 to December 2019 Source: USDA Agricultural Market Service Terminal Market Reports.

- High price and low price are available. The difference is not significant. Therefore the middle price is shown.

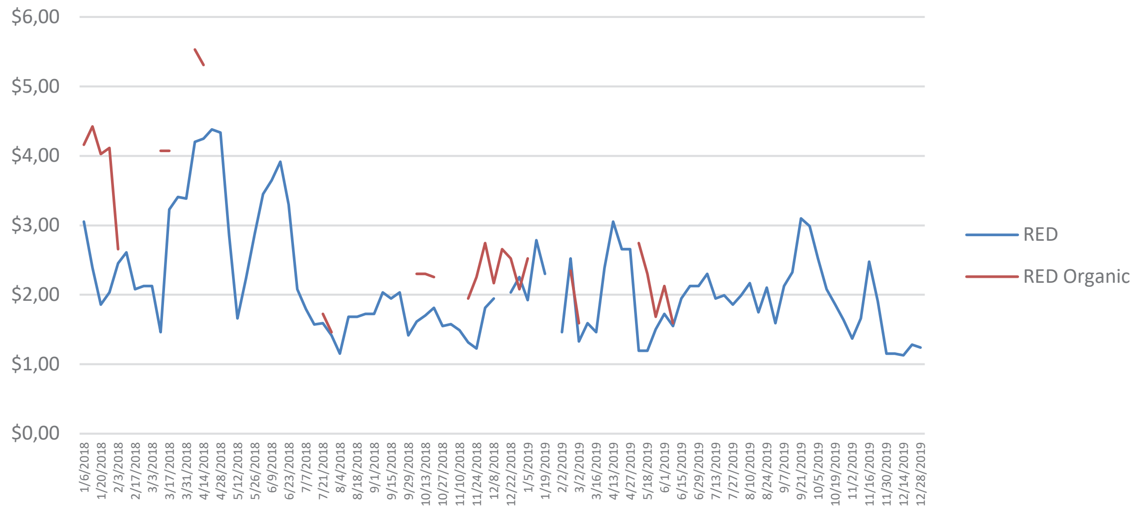


Weekly average wholesale prices (middle price) in US dollar per kg of avocados, by variety, 25lbs 2 layers containers mostly. New York terminal market. From January 2018 to December 2019 Source: USDA Agricultural Market Service Terminal Market Reports.



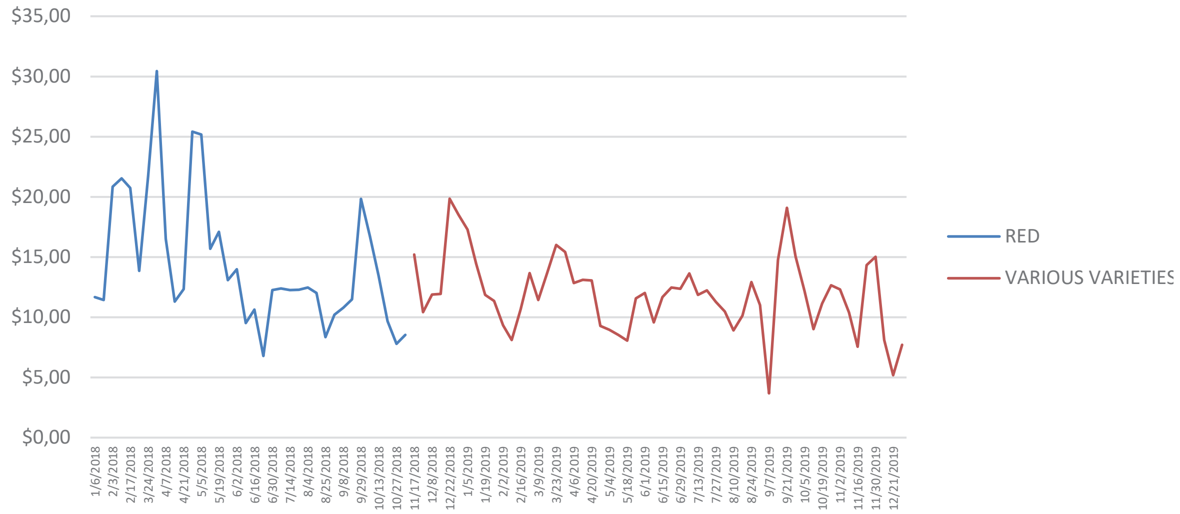
Monthly average producer prices of Spanish avocados, in euro per kg, Hass - Cat. I - Cal. 16-20. From January 2014 to June 2020 Source: DG AGRI - Monthly Market Prices.

Annex 3 Wholesale prices raspberry



Weekly average wholesale prices (middle price) in US dollar per kg of raspberries, by variety, flats 12 6-oz cups with lids mostly. New York terminal market. From January 2018 to December 2019 Source: USDA Agricultural Market Service Terminal Market Reports.

- High price and low price are available. The difference is not significant. Therefore the middle price is shown.



Weekly average wholesale prices (middle price Rotterdam terminal market) in US dollar per kg of raspberries in the Netherlands, by variety, packet by 12 125 mg cups. From January 2018 to December 2019 Source: USDA Agricultural Market Service Terminal Market Reports.

- High price and low price are available. The difference is not significant. Therefore the middle price is shown.

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Report WPR-1049

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