Large-scale greenhouse production in Iceland for export: what are the key challenges?

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Iceland has unlimited, renewable energy:

- Could it grow food for large-scale export?
- The only way it could be possible would be a in a controlled environment
- A giga-plant factory or a giga-greenhouse

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The Greenhouse Horticulture Unit of Wageningen

- Is the largest (and best) concentration of greenhouse specialists in the world
- Owns greenhouse climate simulators able to predict productivity and resource requirement of all types of greenhouses and plant factory systems, everywhere in the world
- With partner Wageningen Economic Research has developed models and databases for integral cost assessment of greenhouse crops

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Questions

- Which crops could be produced competitively at a giga scale?
- How is productivity improved by the technology of the growing system?
- How is resource use affected by climate?
- Which potential export markets to consider?

Project overview

1. Crop selection
2. Technical scenario design and resource use calculations
3. Cost calculations (investment and operational cost)
4. Market selection and data collection
5. Integration and presentation of the results

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Crop selection: Methodology

1. A pre-selection of 32 crops widely consumed in the occidental diet was made that included: vegetables, fruits, cereals and tubers
2. A list of 12 soft constraints (selection criteria) was decided to score each crop between 0-10
3. A selection of 10 experts weighed the 12 constraints and obtained a score for each crop
4. The final score for each crop was obtained averaging the value from the 10 users
5. Final list was not satisfactory for Earth 2.0 because it lacked highly nutritious crops

Microsoft Excel
ro-Enabled Works

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Crop selection: Constraints

- Harvest index
- Space and time efficiency (Yield/(Space*Period))
- There is large experience in cultivating this crop in climate controlled enviroments
- Suitability for mechanization and automation of crop operations
- 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

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1. Crop selection:

46th International Conference on Environmental Systems
10-14 July 2016, Vienna, Austria
ICES-2016-206

Choosing crops for cultivation in space

Tom Dueck[1], Frank Kempkes[2], Esther Meinen[3], Cecilia Stanghellini[4]
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Future space missions require bio-regenerative life-support systems. Eating fresh food is not only a fundamental requirement for survival but also influences the psychological well-being of astronauts operating on long duration space missions. Therefore the selection of plants to be grown in space is an important issue. Part of the EDEN ISS project entails the development and application of a methodology to select suitable plants for cultivation on-board the ISS and the Neumayer III Antarctic station, a space analogue site. A methodology was developed taking physical and physiological constraints, and human well-being (quality) aspects into account. It includes a framework for the selection process, a list of relevant criteria based on plant characteristics, engineering constraints and human nutrition and psychology. It entails a scoring system to assess and weigh these criteria for each crop, in order to rank the chosen crops. Human quality aspects, such as taste, texture and appearance were related to the well-being of astronauts. Yield aspects combined crop yield and growth efficiency in time and space, while production aspects concentrated on physical constraints of the planned growth modules and the technical aspects of cultivation. The methodological framework used for the selection of plants was based on several approaches. Physical and physiological constraints determine whether or not the crop can be cultivated in space (and/or in Antarctica) and all other parameters are prioritized according to human quality aspects, yield or production aspects that were ranked according to pre-selected weighing factors. This yielded a ranking of the crops to be grown in a controlled ecological life support system. A description of the methodology and its results with a choice of crops related to the aims of the EDEN ISS project are given and will be discussed.

The crop selection tool was based on the methodology proposed by Dueck et al., 2016

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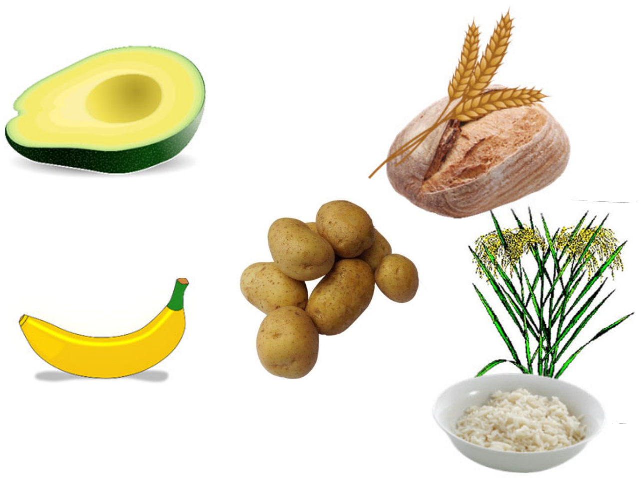
1. Crop selection:

Typical greenhouse crops with high vitamin content

Traditional open field crops with high protein/calory content



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High-tech greenhouse vs Indoor farm

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HPS lamps vs LED´s

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2. Technical Scenarios

- 3 different technical scenarios were studied for 2 different locations

	Lamp type	Location
Glass greenhouse	HPS lamps	Keflavík
		Akureyri
	LEDs	Keflavík
		Akureyri
Indoor farm	LEDs	-

For most crop/site combinations, we analysed various light intensities

- The design for each of the different technical scenarios was based on a climate data analysis performed for the two locations

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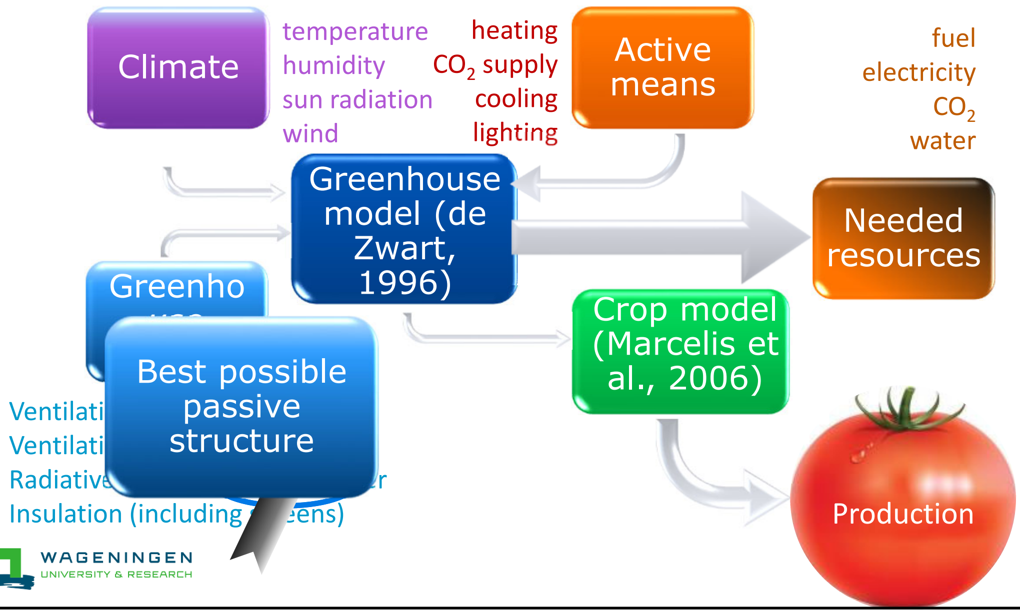
The adaptive greenhouse method (Vanthoor, 2011):



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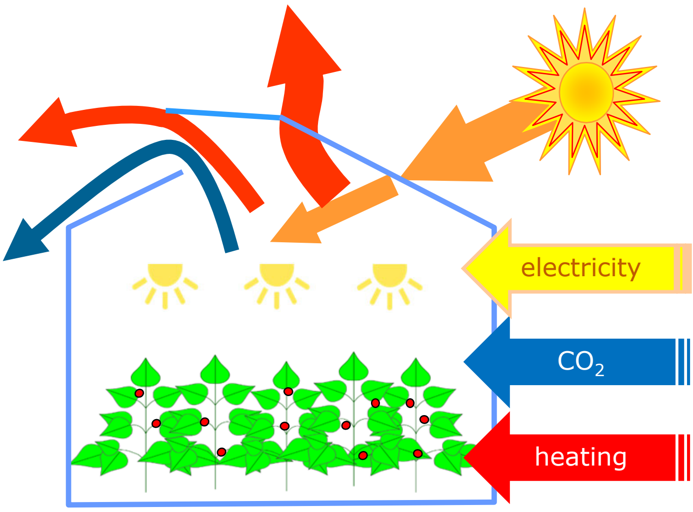
Productivity calculation



- Greenhouse climate/indoor farm model **Kaspro** (**de Zwart,1996**) to calculate resource requirement to maintain desired conditions
- Crop model [tomato **Intkam (Marcelis et al, 2006**)/lettuce (**Van Henten et al. 1994**)] to calculate yield
- For the other crops yield is estimated from calculated photosynthesis

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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

Effect of crop, location, lighting and growing system

lettuce		Keflavik		Akureyri		Indoor farm
		HPS	LED	HPS	LED	LED
Electricity	GWh/(ha·y)	5.7	3.6	5.8	3.6	8.3
Heating	GWh/(ha·y)	2.4	3.5	2.7	3.7	
Total energy	GWh/(ha·y)	5.7	3.6	5.8	3.6	8.3
CO_2	t/(ha·y)	374	360	335	322	217

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Glasshouses always have lower energy requirements than indoor farms... regardless of location

LED lighting uses less electrity than HPS but required more heating

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3. Cost calculations

Operational cost (other than resources) and capital costs have been determined following the method of "Quantitative information for the glasshouse horticulture 2019"


Quantitative Information on Dutch greenhouse horticulture 2019

Key figures on vegetables – cut flowers – Pot and bedding plants crops
26th Edition in English

M.G.M. Raaphorst[1] (Editor), J. Benninga[2] and B.A. Eveleens[1]
1. Wageningen University & Research, Business Unit Glastuinbouw, 2. Wageningen Economic Research

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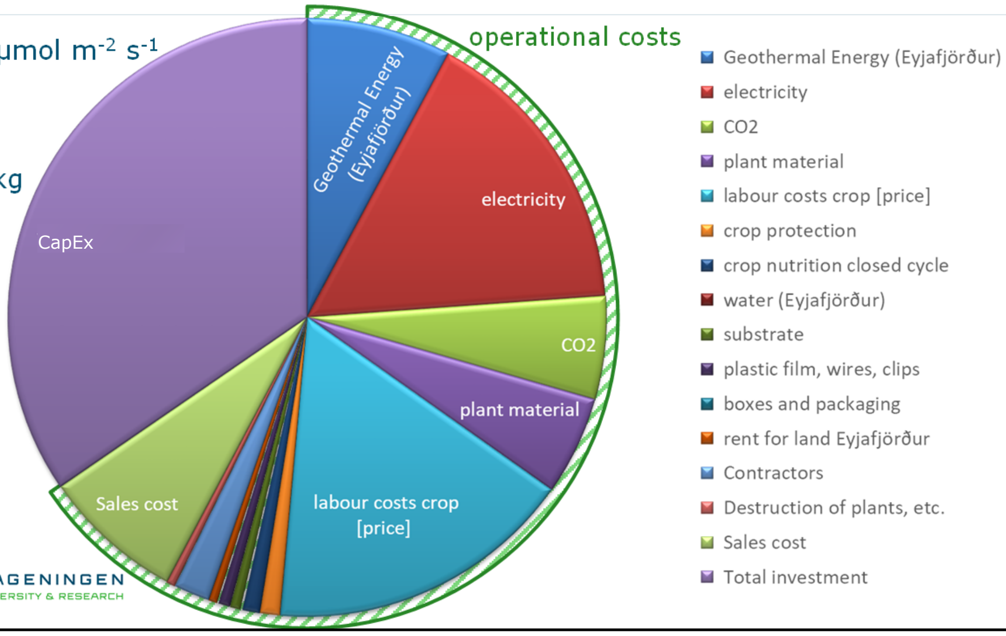
Cost distribution example in Iceland

HPS 250 µmol m^{-2} s^{-1}
Akureyri

Total:
149 ISK/kg



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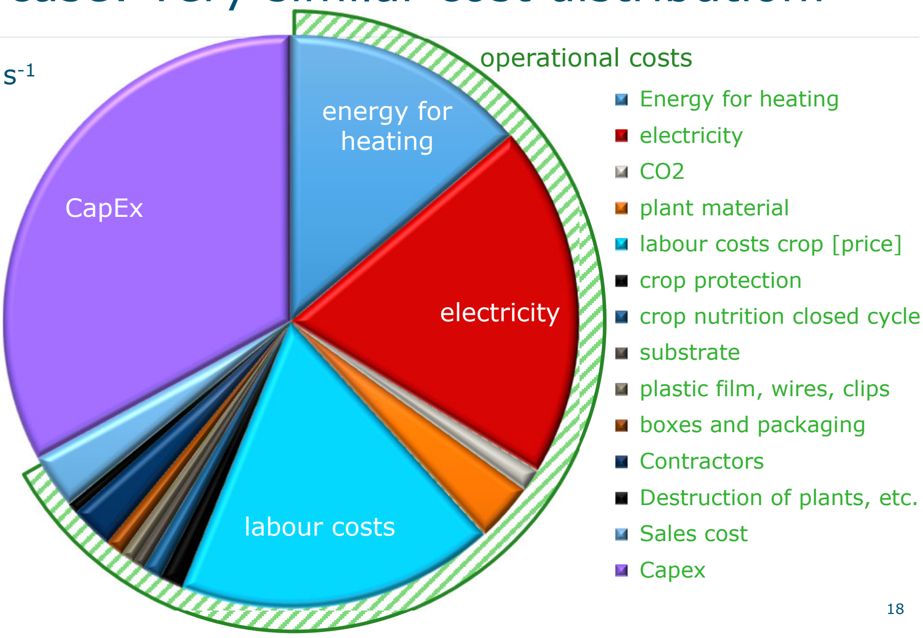
The Dutch case: very similar cost distribution!

HPS 200 µmol m^{-2} s^{-1}
The Netherlands

Total:
139 ISK/kg



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CapEx, electricity/heating and labour represent the main share of costs and the targets to lower the cost price

Giga scale can decrease CapEx and energy prices; automation and robotization, labour costs

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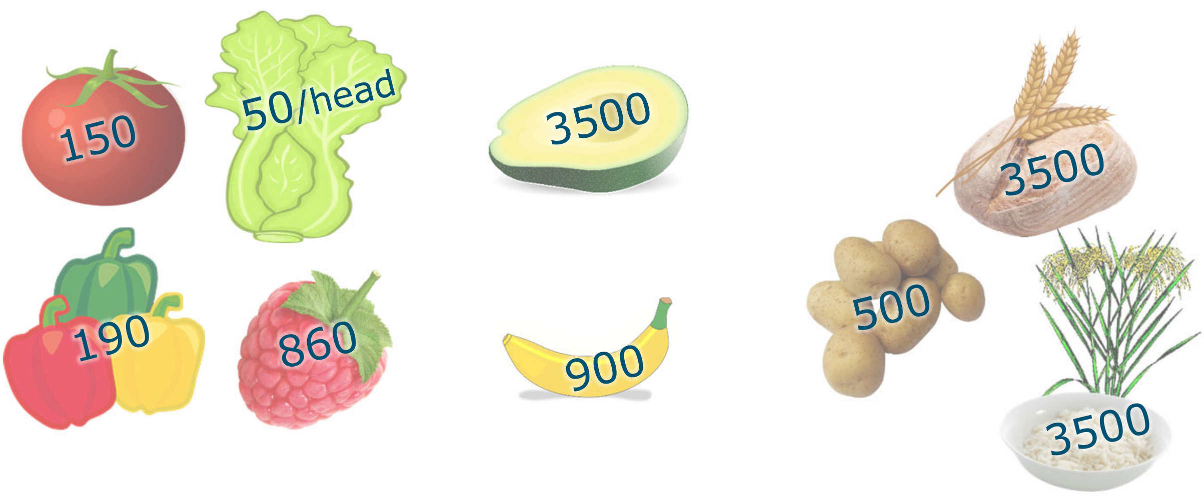
Cost price in Iceland (ISK/kg, best case)



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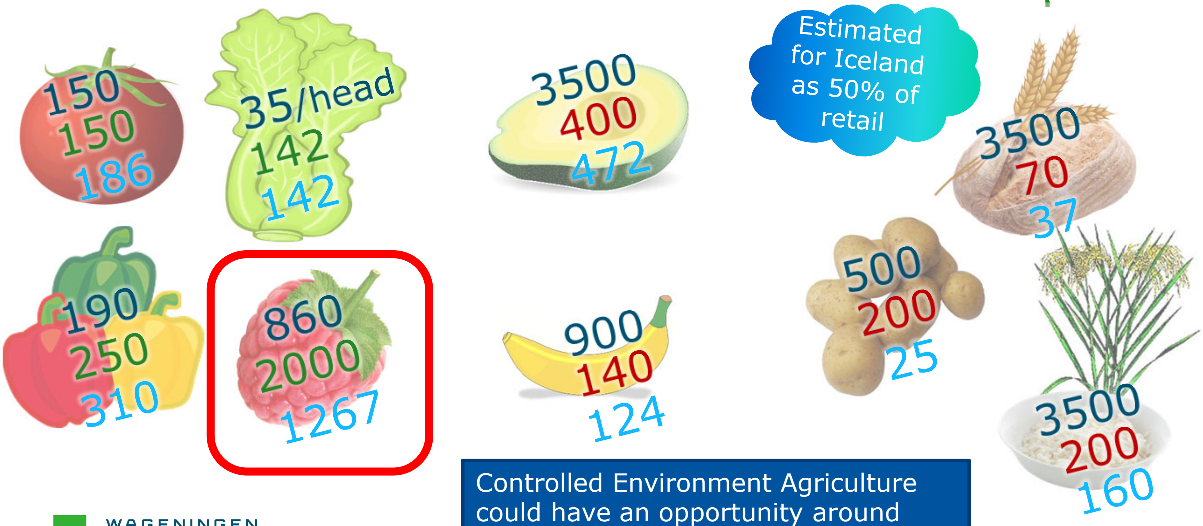
Cost price in Iceland (ISK/kg, best case)...

...vs local and Dutch wholesale price



Controlled Environment Agriculture could have an opportunity around berries in Iceland

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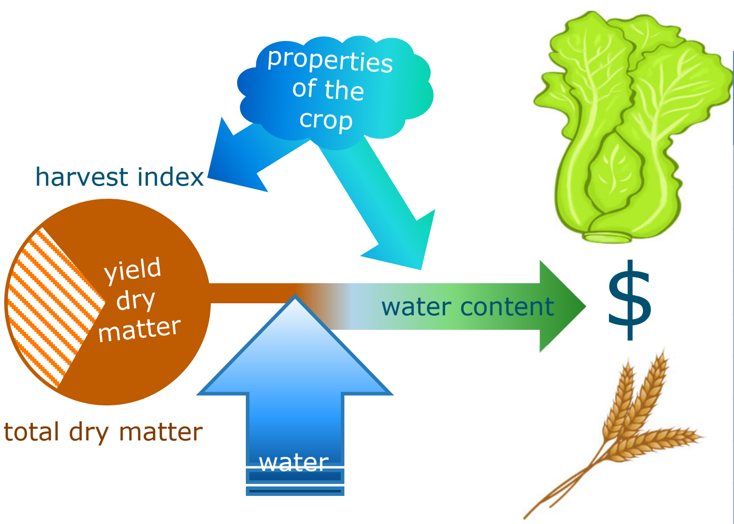
High water content/high harvest index make money!



	dry matter %	harvest index %	$\frac{kg_{yield}}{kg_{dry}}$
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

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4. Market selection: the "market explorer"* 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	Insights on the 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	Costs of trading across borders	World Bank
Apparent availability	Low	Average over last 3 years	FAOStat
Availability development	Low	Yearly, based on 10 years	FAOStat

The 8 most promising markets selected for each crop, then for each combination:

- Wholesale and producer prices
- Transportation costs (sea and air freight)

*Business case for large scale vegetable and fruit production in greenhouse facilities in Iceland for the global market (Baeza & Dijkxhoorn, 2021)

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Lettuce is highly producive and cultivation can be fully automated!

all prices: ISK/Head

Best cost price 35/head	transport	total	local wholesale	profit
Slovenia	46.5	81.5	142.2	60.8
U.S.A.	108.4	143.4	352.1	208.6
Italy	46.5	81.5	178	96.5
Netherlands	46.5	81.5	142.2	60.8
Denmark	46.5	81.5	142.2	60.8
Germany	46.5	81.5	142.2	60.8
Hong Kong	108.4	143.4	50.8	-93
Sweden	46.5	81.5	142.2	60.8

Lowest cost price in Iceland 35 ISK/head

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Berries and other high value crops (herbs) can be profitable too

all prices: ISK/kg

Best cost price 831.7/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

Lowest cost price in Iceland 831.7 ISK/kg

SPOILER: Air freight costs seem to ensure little/no potential for export of the other fresh products

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Air freight from Iceland is sustainable for high value products

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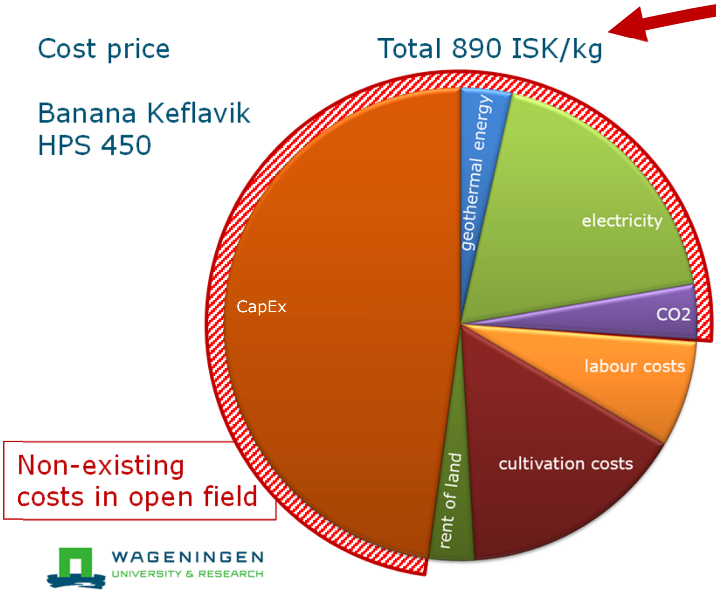
Most traditional field crops are not profitable under CEAC



	Wholesale price ISK/kg	Transport cost ISK/kg
Slovenia	123.92	4.22
Netherlands	123.92	4.22
U.A.E.	84.49	8.45
U.S.A.	123.92	4.22
Germany	123.92	4.22
Belgium	123.92	4.22
Finland	123.92	4.22
France	123.92	4.22

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Critical future developments

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Game changing scenarios

Negative for the plan

- "greening" of production in rich countries
- Higher air freight fares

Positive for the plan

- New "high value" crops
- Improved cooling technology
- Climate change limiting open field cultivation areas (draught, diseases, floods, etc.)

Review article
Review: Climate change impacts on food security- focus on perennial cropping systems and nutritional value
Courtney P. Leisner

Review
Potential impacts of climate change on vegetable production and product quality – A review
Mehdi Benyoussef Bisbis, Nazim Gruda, Michael Blanke

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Summary: Use of our model

- Evaluate best design/investment dependent on local climate and input costs
- Evaluate how productivity can be enhanced through some technical investments
- "What if" productivity could be increased by application of artificial intelligence, improved breeding etc
- "What if" running costs could be decreased by application of artificial intelligence
- Assessment of potential for export to countries based on:
  - Import price & GDP
  - Import volume & trend
  - Tariffs

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Conclusions: what we have found out

- Glasshouse production (not indoor) has in all cases the lowest cost-price and lowest energy requirement
- The cheap (and sustainable) energy of Iceland gives it a potential competitive advantage **ONLY** for the crops that are cultivated in greenhouses also elsewhere
- But then such crops require air freight, which makes them in most cases uncompetitive in export markets
- Potentially competitive crops are very high-value ones, such as raspberry and lettuce.

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Conclusions: outlook

- A significant reduction of air freight costs could expand the number of fresh vegetable crops that could be economically exported
- As energy (elecricity + heating) accounts for about 30% of the operating costs, a reduction of fees would also be helpful
- Glasshouse production for the internal market can be profitable for vegetables crops and could be expanded (see next two slides)

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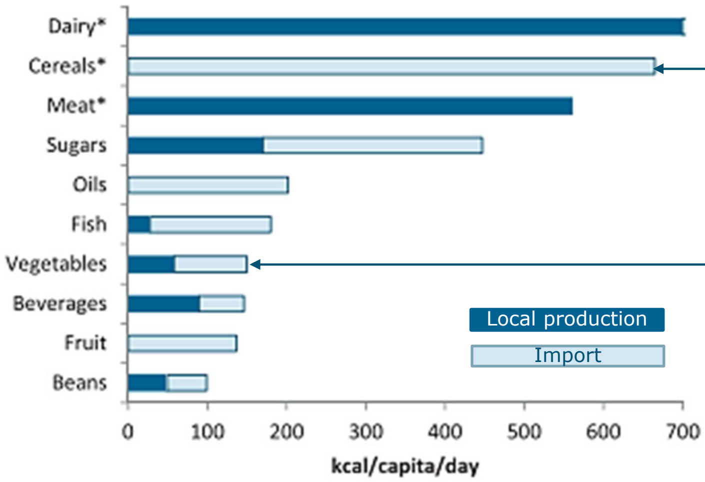
Which food is imported in Iceland? and where could be a competitive advantage?



Extensive agriculture, field production
No

Doubtful
Field production: roots and tubers and cabbages
Greenhouse production (fresh consumption)
Most likely

https://iopscience.iop.org/article/10.1088/1748-9326/11/11/115004

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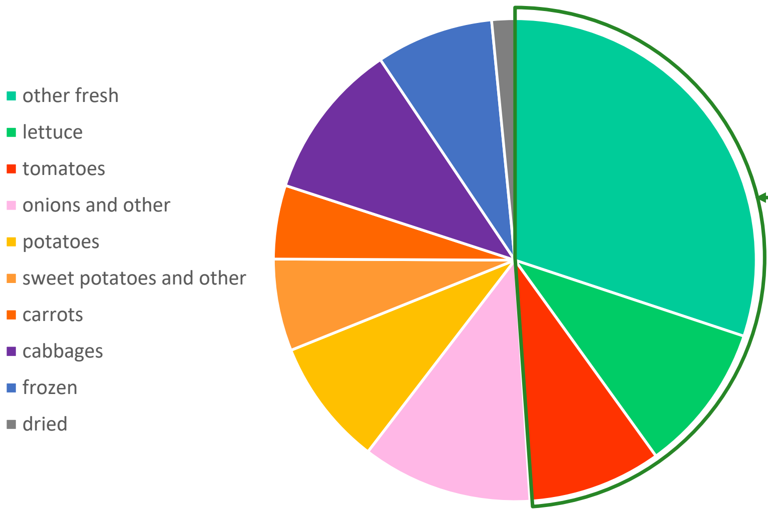
Distribution of vegetable import



Total value of import in 2019 = 35 million US$

Almost 50% (of value) is fresh greenhouse products

https://trendeconomy.com/data/h2?commodity=07&reporter=Iceland&trade_flow=Export,Import&partner=World&indicator=NW,TQ,TV&time_period=2018,2019

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