A greenhouse design for Mexico

The case of La Huerta, Aguascalientes

Anne Elings[1], Jouke Campen[1], Nieves García Victoria[1] & Olga van der Valk[2]

[1]Wageningen UR Greenhouse Horticulture, Wageningen/Bleiswijk [2]Landbouw Economisch Instituut, The Hague

Ministerie van Economische Zaken

Rapport GTB-1223

Abstract NL

Deze studie doet verslag van de milieu en economiche gevolgen van verschillende technologische niveaus voor het groenteteeltbedrijf La Huerta in Aguascalientes, Mexico. Zes technologische niveaus, variërend in kasdekmateriaal, verwarming, koeling, aanwezigheid van energieschermen, type substraat, gebruik van recirculatie, en gebruik van CO_2 zijn doorgerekend. Een hoger technologisch niveau leidt tot een hogere productie. Het laagste technologische niveau heeft de langste terugverdientijd. Het mid-tech niveau dat momenteel door La Huerta wordt gebouwd is in termen van terugverdientijd de meest optimale keuze. Het watergebruik varieert weinig tussen de technologische alternatieven. Maar de waterbenuttingsefficiëntie neemt sterk toe met een toenement technologisch niveau aangezien de produktie sterk stijgt. De energiebenuttingsefficiëntie neemt af met toenemend technologisch niveau als gevolg van het relatief sterk stijgende energieverbruik. Tuinders die aan een workshop deelnamen waardeerden de verwachtte toename in productie en productkwaliteit, en verwachtten daarom een hoger inkomen, een betere controle over het kasklimaat en andere productieomstandigheden, en een lagere milieudruk. Ze benadrukten de noodzaak van een optimaal ontwerp voor plaatselijke omstandigheden, rekening houden met de variatie in weersomstandigheden in de tijd, en de afhankelijkheid van de markt. Kennis werd als een cruciale factor beschouwd.

Abstract UK

This study reports on the environmental and economic impacts of different technological levels under a variety of conditions, for the La Huerta farm in Aguascalientes, Mexico. Six technology levels were evaluated, varying in covering material, heating, cooling, the presence of thermal screens, the type of substrate, the use of re-circulation, and the use of CO_2 enrichment. Increased technology results in increased production. The low-tech options have the longest pay-back time. In terms of pay-back time, the mid-tech greenhouse that is currently under construction at La Huerta, is an optimal solution. Water use does not vary much in absolute terms among the technical alternatives, but as the production does, the water use efficiency strongly increases with increasing technology level. The energy use efficiency decreases with increasing technology level, due to the strong increased use of energy in absolute terms. Growers at a workshop appreciated the expected increase in production and product quality and therefore expected income increase, a better control of the climate and production system, and lower environmental impact. They stressed the need for an optimal design for local conditions, also given temporal climate variation, and the dependency on the market situation. Knowledge was considered a crucial factor.

Resumen Español

El impacto medioambiental y económico derivado de la transición tecnológica en horticultura protegida ha sido calculado con ayuda de modelos usando datos de la finca “La Huerta” en Aguascalientes, México. Se evaluaron escenarios correspondientes a seis niveles de tecnología (material de cubierta, calefacción, refrigeración, pantallas térmicas, substrato, reutilización de aguas de drenaje y dosificación de CO_2.). Los resultados muestran que la producción aumenta con el nivel tecnológico. Los escenarios de baja tecnología son de larga amortización. El invernadero en construcción en La Huerta, de tecnología media, es una solución de óptima amortización. El uso absoluto de agua por m^2 varía poco entre escenarios, pero las diferencias en producción causan un fuerte aumento en eficiencia de uso de agua con el nivel de tecnología. Inversamente, la eficiencia energética disminuye cuando el nivel tecnológico aumenta. Los resultados fueron discutidos en un taller con productores, quienes valoraron el método y los resultados positivamente. Hicieron hincapié en la necesidad de un diseño óptimo para condiciones locales, que considere variación climática a largo plazo y dependencia del mercado. El conocimiento fue considerado un factor de crucial importancia para la transición tecnológica.

Table of Content

Summary

Background: This study reports on the environmental (e.g., water and energy use) and economic (e.g., production level, pay-back time of investments) impacts of the implementation of different technological modules under a variety of conditions, for the La Huerta farm in Aguascalientes, Mexico. The project focused on the level of technology at Mexican side that match with the Dutch supply and knowledge: mid- and high tech companies, and the project has to be seen in the context of the strive to intensify collaboration between the Mexican and Dutch horticultural sectors.

Approach: The adaptive greenhouse approach was followed, which defines a number of objectives (e.g., minimal water use, minimal energy use, high production, high product quality), required functions (e.g., energy use, heating, cooling, reduction of energy loss, cultivation systems, crop protection systems, labour), possible greenhouse designs, and subsequently evaluates their sustainability on the basis of economic, water and energy parameters. The results of the study was discussed with Mexican growers at the La Huerta farm. Six technology levels were evaluated, ranging from low to high-tech, and varying in covering material, heating, cooling, the presence of thermal screens, the type of substrate, the use of re-circulation, and the use of CO_2 enrichment.

Production levels: The climate in Aguascalientes is suitable for horticultural production under protected conditions, however, heating in winter time, when temperatures are low, considerably improves the production level. A further increase in production is realized through the day time use of CO_2 flue gasses from the heating system. Diffuse glass that realizes a better light spectrum and thermal screens that realize higher temperatures in winter time are further steps to increase yield.

Economic sustainability: The use of CO_2 flue gasses from the heating system leads to higher variable costs, however, the balance with the increased production is such that these systems have the shortest pay-back time. If CO_2 flue gasses are used in combination with other high-tech options (H), then the pay-back time increases to 3.5 years. The low-tech options has the longest pay-back time (5 years), which reflects the law of diminishing returns. In terms of pay-back time, the mid-tech greenhouse that is currently under construction at La Huerta (M3), is an optimal solution. The reasons for this are the low use of relatively expensive energy and the low price of water.

Water use efficiency: Water use does not vary much in absolute terms among the technical alternatives, but as the production does, the water use efficiency strongly increases with increasing technology level. Application of soilless cultivation increases sustainability in terms of water, and also in terms of nutrient use. This can be further optimised by re-use of water.

Energy use efficiency: The energy use efficiency decreases with increasing technololgy level, due to the relatively strong increased use of energy in absolute terms. The sustainability in terms of energy will be improved if for instance use can be made of geothermal sources.

Farmers' views: Farmer raised a number of points at the workshop, where the findings of the study were discussed. First of all, they appreciated the expected increase in production and product quality and therefore expected income, and better control of the climate and production system. This depends, however, on the optimum adaptation of the desing to the local circumstances, and the expected higher cost and longer delivery time if supplies have to be imported. Also rising energy costs were a concern. But Aguascalientes has the possibility to use geothermal energy.

The reduced water use and pollution of the outside environment with chemicals were considered important advantages.

Alliances between chain actors and tapping new markets (e.g., export) were considered important for economic sustainability. However, lack of capital, high costs, unstable or inert markets, lack of organization and high risks were identified as factors that negatively influence the income generation by farmers.

Finally, it was recognized that protected cultivation is very knowledge-intensive and that training at all levels is crucial.

Implications for suppliers: Suppliers should take notice of the positive and negative aspects of technological innovations that were seen by the Mexican growers. The importance of these points lies in the fact that they must be built upon (the positive points) or dealt with (the negative points). Positive points offer important building blocks for transition. If a negative point made is valid, then a solution must be found, if it concerns only a perceived problem then an awareness activity must be organized, and if an easy solution to a problem exists, then naturally this solution must be offered.

Resumen

Objetivos y antecedentes: Con el objetivo de facilitar la toma de decisiones en cuanto a transición tecnológica en la horticultura protegida mexicana, en este estudio se ha calculado el impacto medioambiental y el resultado económico derivados de la implementación de ciertos avances tecnológicos. Los datos provienen de la finca “La Huerta”, en Aguascalientes, México, que ha servido como ejemplo. El impacto medioambiental se define en términos de uso de agua y energía. El impacto económico en términos de productividad y amortización de inversiones. El estudio se centró en tecnología aplicable en México que coincide con la oferta y conocimiento holandeses para tecnología media-alta, en el marco de esfuerzos para intensificar la colaboración entre el sector hortícola mexicano y el holandés

Enfoque: El enfoque seguido es el del “invernadero adaptativo”, que integra modelos económicos, climáticos y fisiológicos en un sistema de cálculo. Definiendo objetivos (ejemplos: uso mínimo de agua, uso mínimo de energía, alta producción, alta calidad), definiendo las funciones requeridas (ejemplos: uso de energía, calefacción, refrigeración, reducción de pérdida energética, sistema de cultivo, protección de cultivos, mano de obra) y definiendo los diseños posibles de invernadero, los modelos permiten evaluar la viabilidad de distintas combinaciones en base a parámetros acuáticos, económicos y energéticos. Así se evaluaron seis escenarios correspondientes a sendos niveles de tecnología (de baja a alta), variando en material de cubierta, calefacción, refrigeración, presencia de pantallas térmicas, tipo de sustrato, recirculación de aguas de drenaje, y enriquecimiento del ambiente con CO_2. Los resultados del estudio se discutieron con productores mexicanos en un taller en la finca “La Huerta”.

Productividad: El clima en Aguascalientes es adecuado para la producción hortícola protegida. La calefacción en invierno, así como el uso durante el día de CO_2 procedente de los humos de combustión para el sistema de calefacción, mejoran considerablemente la productividad. Vidrio difuso que mejora la distribución de la luz y pantallas térmicas para reducir pérdida de calor en invierno son más medidas rentables para aumentar la productividad.

Sostenibilidad económica: El uso de CO_2 de los humos de combustión de la caldera aumenta los gastos variables, sin embargo, por el aumento de la producción que conlleva tienen la amortización más corta. Si el uso de CO_2 se combina con otras opciones de alta tecnología, el tiempo de amortización aumenta a 3,5 años. Las opciones de baja tecnología tienen la amortización más larga (5 años), lo que refleja la ley de los rendimientos decrecientes. En cuanto a amortización, el invernadero de tecnología media que se encuentra actualmente en construcción en La Huerta, es una solución óptima. Las razones son el uso bajo de energía relativamente cara y el bajo precio del agua.

Uso eficiente del agua: El uso de agua no varía mucho en términos absolutos entre los escenarios estudiados, pero como la producción aumenta, la eficiencia del uso del agua aumenta fuertemente con el nivel de tecnología. El cultivo sin suelo aumenta la sostenibilidad en términos de uso de agua, y también en términos de uso de los nutrientes. Esto puede optimizarse aún más mediante la reutilización del agua de drenaje, una opción tecnológica compatible con la mayoría de escenarios en los que se contempla cultivo sin suelo.

Eficiencia energética: La eficiencia del uso de energía disminuye al aumentar el nivel de tecnología, debido al fuerte aumento de energía en términos absolutos, mayor que el aumento de producción. La sostenibilidad en términos de energía mejorará si por ejemplo se puede acceder a energía geotérmica, opción realista en Aguascalientes.

Opinión de los agricultores: Los asistentes al taller valoraron muy positivamente el método y las previsiones de aumento de producción, la calidad del producto y los ingresos. Ven en la tecnología posibilidades para un mejor control del sistema climático y de la producción. El diseño debe adaptarse siempre a las circunstancias locales. Se temen costes más altos y largos tiempos de entrega si los suministros tienen que ser importados. El aumento de los costos de energía son otra preocupación. Pero Aguascalientes tiene la posibilidad de utilizar energía geotérmica. La reducción en la utilización de agua que conlleva menor contaminación del medio ambiente con nutrientes y productos de protección vegetal se consideraron importantes ventajas. Alianzas entre actores de la cadena y la exploración de nuevos mercados

(por ejemplo, exportación), se consideran importantes para la sostenibilidad económica. Sin embargo, falta de capital, altos costos, mercados inestables o inertes, falta de organización y el alto riesgo fueron identificados como factores que influyen negativamente en la generación de ingresos para los agricultores. Por último, se reconoció que el cultivo protegido es muy intensivo en conocimiento y formación a todos los niveles.

Implicaciones para los proveedores: Los proveedores deberían tomar seria nota de los aspectos positivos y negativos de las innovaciones tecnológicas como las ven los agricultores mexicanos: construir sobre los puntos positivos (que ofrecen elementos importantes para la transición) y solucionar los puntos negativos. Problemas “percibidos”, pueden solucionarse mediante actividades de sensibilización.

Samenvatting

Achtergrond en doel: Technologische transitie in de mexicaanse bedekte teelten is complex. Een studie is uitgevoerd om inzicht te verschaffen in de milieubelasting (bv. water-en energieverbruik) en economische gevolgen (bijv. productieniveau, terugverdientijd van investeringen) van verschillende technologische keuzes. Hiervoor zijn gegevens gebruikt van het groenteteeltbedrijf “La Huerta” in Aguascalientes, Mexico. Het project richtte zich op het niveau van de technologie aan Mexicaanse zijde die overeenkomen met het Nederlandse aanbod en kennis: mid-en high-tech bedrijven. De studie moet worden gezien in de context van inspanningen om de samenwerking tussen de Mexicaanse en Nederlandse tuinbouw te versterken.

Aanpak: De “adaptieve kas” aanpak is gevolgd. Die definieert een aantal doelstellingen (bijvoorbeeld, minimaal gebruik van water, minimaal energieverbruik, hoge productie, hoge kwaliteit van het product), de vereiste functies (bijvoorbeeld energieverbruik, verwarming, koeling, vermindering van energieverlies, teeltsystemen, gewasbescherming systemen, arbeid) en mogelijke kas ontwerpen. Het model vervolgens beoordeelt de duurzaamheid van opties op basis van economische, water en energie parameters. Zes scenarios, ieder met een technologieniveau zijn geëvalueerd, variërend van laag naar hoog-tech, en variërend in kasdekmateriaal, verwarming, koeling, aanwezigheid van thermische schermen, type substraat, re-circulatie van drainwater en het gebruik van CO_2. De resultaten zijn besproken met Mexicaanse telers tijden een workshop in “La Huerta”.

Productie niveaus: Het klimaat in Aguascalientes is geschikt voor beschermde tuinbouw. Verwarming in de winter en CO_2 uit rookgassen van de CV-installatie doseren overdag verbeteren aanzienlijk het productieniveau. Een verdere toename van de productie wordt gerealiseerd door diffuus glas dat een betere lichtverdeling en thermische schermen die energie verliezen verminderen zijn verdere stappen om de opbrengst te verhogen.

Economische duurzaamheid: Het gebruik van CO_2 rookgassen uit de verwarmingsinstallatie leidt tot hogere variabele kosten echter door de verhoogde productie hebben deze systemen de kortste terugverdientijd. Als de CO_2 uit rookgassen wordt gebruikt in combinatie met andere high-tech opties, dan stijgt de terugverdientijd tot 3,5 jaar. De low-tech opties heeft de langste terugverdientijd (5 jaar), die de wet van de afnemende meeropbrengst weerspiegelt. In termen van terugverdientijd, de medium-tech kas die momenteel in aanbouw is in La Huerta is een optimale keuze. De redenen hiervoor zijn de lage gebruik van relatief dure energie en de lage prijs van water.

Water efficiëntie: Watergebruik varieert niet veel in absolute zin tussen scenario’s, maar vanwege het effect van technologie op de productie, neemt de efficiëntie van water gebruik sterk toe met toenemende technologisch niveau. Teelt op substraat verhoogt de duurzaamheid op het gebied van water, maar ook in termen van gebruik van voedingsstoffen. Dit kan verder worden geoptimaliseerd door hergebruik van drainwater, een technologie dat is compatibel met de meeste scenario’s die uitgaan van teelt op substraat.

Energie efficiëntie: De energie efficiëntie afneemt met toenemende technologieniveau door de relatief sterk verhoogd energieverbruik in absolute termen. De duurzaamheid in termen van energie kan verbeteren door de inzet van geothermische energie, een realistische optie in Aguascalientes.

Meningen van telers: Tijdens de workshop waar de resultaten werden besproken spraken telers hun waardering voor de methode uit. De berekende toename van de productie en de kwaliteit en dus de verwachte opbrengsten, alsmede een betere controle van het klimaat en productiesysteem vonden ze interessant. Benadrukt werden de noodzaak van optimale aanpassing van het kasontwerp aan de lokale omstandigheden. Telers verwachten hogere kosten en langere levertijden als systemen moeten worden geimporteerd. Ook de stijgende energiekosten waren een punt van zorg. Maar Aguascalientes heeft de mogelijkheid om geothermische energie te gebruiken. De verminderde watergebruik en verlaagde milieubelasting met chemicaliën werden beschouwd als belangrijke voordelen. Allianties tussen ketenactoren en het aanboren van nieuwe markten (bijvoorbeeld export) werden genoemd als belangrijk voor de economische duurzaamheid. Gebrek aan kapitaal, hoge kosten, instabiele of inerte markten, gebrek aan organisatie en hoge risico’s werden geïdentificeerd als factoren die

negatieve gevolgen kunnen hebben voor de inkomsten. Tot slot werd erkend dat beschermde teelt is zeer kennisintensief en dat de opleiding op alle niveaus is van cruciaal belang.

Implicaties voor leveranciers: Leveranciers kunnen kennis nemen van de positieve en negatieve aspecten van technologische innovaties zoals deze gezien worden door de Mexicaanse telers. Deze aspecten kunnen worden gebruikt (de positieve) of behandeld (de negatieve). Positieve aspecten bieden belangrijke bouwstenen voor technologische transities. Negatieve, geldige aspecten dienen te worden opgelost. Negatieve problemen in de esfeer van “perceptie van de teler” kunnen worden opgelost door bewustzijn vergrotende activiteiten.

1 Introduction

1.1 Background

Protected greenhouse horticulture in Mexico is growing strongly. Flowers are produced mainly for the domestic market, while there is much export of (fruit) vegetables to the USA and Canada (García Victoria *et al.* 2011). The level of technology varies from very low at a multitude of small farms to state-of-the-art in some agro-parks.

The Dutch industry is involved in the Mexican horticultural sector through the supply of planting materials, greenhouse installations, biological control agents, and knowledge. A study on the horticultural sector was commissioned by the Dutch Agricultural Councellor in Mexico (García Victoria *et al.* 2011), and Wageningen UR is, amongst others, involved with the Agrosfera Agropark project in Aguascalientes, while development of more Metropolitan Food Clusters have been initiated (van Mansfeld *et al.* 2012). There is a strong Dutch interest to expand operations in the growing Mexican market, as reflected in the strategy of Greenport Holland International and individual companies. The MexiCultura project was started recently to solve bottlenecks for Mexican growers through joint development of integrated sustainable solutions, transfer of experiences and know-how, and increase of product quality and productivity while maintaining food safety (http://www.floriade-dialogue.com/webfm_send/197). A large number of private companies collaborate in the MexiCultura project, which focuses on the states of Sinaloa, Aguascalientes and Queretaro.

1.2 Transitions

Technology transition paths are complex. Mexican growers signal that various modules (greenhouse constructions, water collection systems, pumps, computer systems, crop and pest management practices) have to be up-graded gradually, and that investments must be cost-effective. They also have to remain in balance, and improve e.g., environmental sustainability and product quality to better meet modern code of conduct requirements.

Figure 1, taken from García Victoria *et al.* (2011) gives a schematic representation of the variety of horticulture farm types that are found in Mexico. The x-axis distinguishes farms on the basis of their technology level, and the y-axis does this on the basis of their market orientation. The y-axis moves from local (municipality) oriented to state market, national market and export market. On the whole, farm types move from low-tech farms that produce for the domestic market towards high-tech farms that produce for the export market, but this can not be considered as the development path for all farms. Technological levels and markets sometimes coexist in the same, bigger companies, depending on the achieved produce quality. In general, export orientated farms tend to have a larger size. In this sense, it is important to note the high level of the fragmentation of Mexican farms: a small sized farm will have no more than 1 ha; while most medium sized farms will measure 1 to 3 ha. A large farm measures more than 10 ha.

1. Subsistence farms: small scale (up to 0.5 ha) farms that have set up small (plastic) greenhouse constructions and sell to local markets. This segment is very susceptible to abandoning and very unlikely to invest in further technology improvement and is therefore not interesting for Dutch industry.
2. Small to medium scale (0.5 to 2 ha) vegetable farms that have formed clusters for commercialization of their produce. Dutch experiences in organizing farmers for the market, e.g., examples of collective bulking, grading and development of niche markets by farmer organisations, gives Dutch industry a comparative and marketable advantage.
3. Small to medium scale flower and ornamental farms in the central states of Mexico and Morelos have a need for good varieties, which offers opportunities for Dutch suppliers of young plants. Part of this segment can be expected to change from open field production towards the use shade or greenhouses with low to medium technology.
4. Medium to large vegetable growers are a very attractive group for Dutch involvement. A tailor-made approach that focuses on relevant modules of greenhouse horticulture can help them advance. Vegetable farms are developing

in Central and Western States of Mexico (Jalisco, Michoacán), mainly producing for domestic markets but with the potential to engage in export markets. Depending on current market position and network, and because of the size of the segment, they represent the main potential for technology development. Vegetable farms in the northern states of Mexico (Sonora, Sinaloa) have an already established track record in exporting and are further innovating. They expect technology input suppliers to support them in finding the right product-market combination with best-fit technology. Vegetable growers in Baja California North and South and in Sonora-Sinaloa have a low level of technology but a good exporting record, and require good quality seed and plant material. Newly established vegetable farms in Durango, Chihuahua, Coahuila, San Luis Potosí, and Nuevo León are export-oriented may require a technological upgrade by the Dutch supply industry.

5. In cut flowers, medium to large-scale farms are found in Baja California exporting to the Californian market. Development demands are unknown. This group is of interest to Dutch industry, and is best assisted in an integrated approach.
6. Agroparks are large agro-industries (> 10 ha) that share physical space and infrastructure and operate either independently or in integrated market chains focussing on the export market, mainly the USA and Canada. Interesting for Dutch industry for development of integrated concepts requiring innovative and higher investments. Dutch involvement must be through an integrated approach.

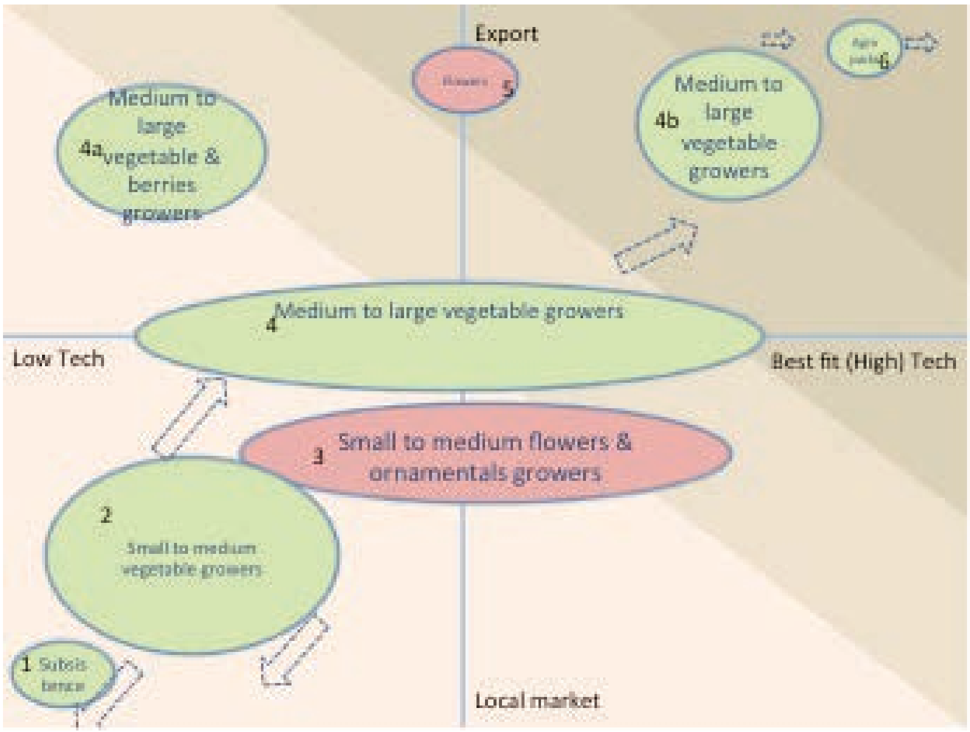


Figure 1. Technology development trends for protected horticulture in Mexico. See text for explanation of 1-6. The size of the oval represents the approximate size of the segment. The arrow gives the assumed development direction of the farm segment. The darker the background colour, the more market opportunities to be found for Dutch input suppliers. Red ovals: flowers; green ovals: vegetables.

1.3 Project goal and approach

The present study concentrates on an existing mid-tech farm in the state of Aguascalientes: La Huerta. This company has been taken as aan example for Farm type 4 of Figure 1. La Huerta is located in the area that is part of one of the envisaged agroparks in the Metropolitan Food Cluster that is considered for Aguascalientes (van Mansveld *et al.* 2012).

1.3.1 Project goals

The general project goal was to describe transition paths for Mexican greenhouse horticulture using real data from an existing Mexican company. More specific goals were to determine the environmental (e.g., water and energy use) and economic (e.g., production level, pay-back time of investments) impacts of the implementation of different technological improvements.

1.3.2 Project approach

The technological improvements have been grouped in “scenarios”, and the mentioned impacts have been calculated under a variety of conditions.

The project focused on the level of technology at Mexican side that matches with the Dutch supply and knowledge: mid- and high tech companies.

The “adaptive greenhouse” approach (Vanthoor, 2011) was followed, which consists of the following steps:

a. Identification of data sources: climate, production, water use, energy, prices, etc.
b. Definition of objectives: e.g., minimal water use, minimal energy use, high production, high product quality.
c. Definition of required functions: e.g., energy use, heating, cooling, reduction of energy loss, cultivation systems, crop protection systems, labour.
d. Description of various economical greenhouse designs.
e. Description of transition paths. These transition paths not only include the greenhouse itself, but also knowledge, institutional infrastructure, post-harvest issues, etc.
f. Workshop with stakeholders in Mexico to increase awareness with the government and private sector, and define market opportunities.
g. Briefing of entrepreneurs in The Netherlands, indicating market opportunities.

The project touches upon the theme ‘climate smart agriculture’ because improved greenhouse designs can reduce the environmental impact (in Mexico: water foot print) of the greenhouse sector while providing sufficient produce for both local and international markets.

1.4 Acknowledgements

The assistance of the Netherands Embassy in Mexico, in particular the Agricultural Councellor Mrs. Gabrielle Nuytens and her office, and the enthousiastic support by La Huerta, in particular Mr.Roberto Javier Farfán Torres and Mr. Juan Pablo Mora Mora, is gratefully acknowledged. The project was funded by the Netherlands Ministry of Economic Affairs and Innovation, under project number BO-10-001-218.

2 Greenhouse types

2.1 Aguascalientes

The project focus was on the State of Aguascalientes, where the acreage of protected cultivation is estimated 16 to 161 ha, depending on the survey (García Victoria *et al.* 2011), and where a Metropolitan Food Cluster is considered (van Mansfeld *et al.* 2012). Protected cultivation in Aguascalientes is characterized by soil cultivation, plastic greenhouse covers, and water heating with gas. Geothermal energy is an option. Growers and other entrepreneurs in Aguascalientes have requested for support in the context of the Agrosfera project (van Mansfeld *et al.* 2012). The growers' aim is to enlarge their business, participate in the agropark in which economic profitability, environmental sustainability, water use efficiency and a low carbon foot print are leading principles.

Figure 2. The location of the State of Aguascalientes in Mexico.

2.2 La Huerta

2.2.1 Farm

Figure 3.Logo of La Huerta.

Rancho Medio Kilo belongs to Frigorizados La Huerta S.A. de C.V. [http://www.lahuerta.com.mx/] in Aguascalientes. Its director is Mr. Carlos Arteago Niepmann, its Farm Manager is Mr. Roberto Javier Farfán Torres, and its R&D Manager is Mr. Juan Pablo Mora Mora.

Rancho Medio Kilo currently has 2 ha of greenhouses with plastic cover in which tomatoes "on the vine" are cultivated on soilless substrate. Heating is realized with hanging gas heaters, and cooling with natural roof ventilation. Thermal screens and CO_2 enrichment are not available. New greenhouses with an acreage of 4.2 ha are under construction (Figure 13.). Improvements will be realized in the form of hot water heating and fan-driven air circulation. The total farm acreage will then be 6.2 ha. The farm is very much interested in improving its sustainability, *e.g.* through recirculation of drainage water (excess irrigation), improved water-use efficiency, and reducing its global foot print.

La Huerta is part of one of the envisaged agroparks within the Metropolitan Food Cluster, being close to major roads, gas pipe-line, a railway junction, the city of Aguascalientes, and hot water springs. A disadvantage is the limited water availability and the dependency on deep wells (van Mansfeld *et al.* 2012).

2.3 Adaptive greenhouse approach

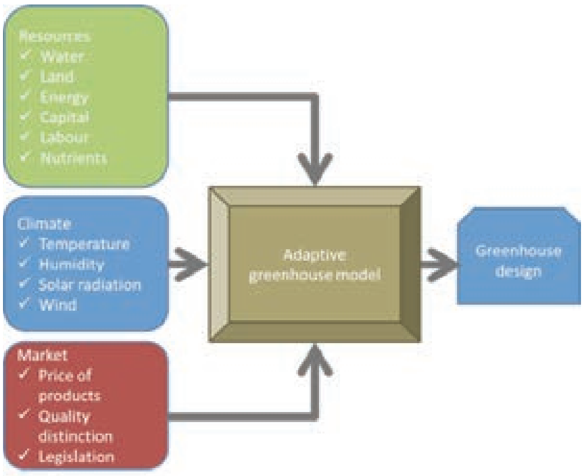


Figure 4. Schematic overview of the approach for the adaptive greenhouse calculations.

Greenhouse design depends on various parameters of which the most crucial ones are presented in Figure 4. The goal is to design a greenhouse which is most economically feasible for a specific crop and given location. At the same time criteria such as water use efficiency, energy saving, and food safety can be considered. Using the adaptive greenhouse model, greenhouse designs are evaluated and compared in terms of economics and resource use by varying installation parameters like heating, cooling, screening, covering etc. Depending on the market prices year-round production is considered. For every design the resources (energy, water, nutrients, labour, carbon dioxide) needed are calculated. The design also determines the level of food safety (reduced pesticide use) which can be achieved. The quality of labour is also directly related to the level of technology applied in the greenhouse design.

The simulation model is based on physical equations describing the heat and mass fluxes associated with greenhouse plant production (De Zwart, 1996). A short description in presented in Annex 1. The dynamic simulations consider all heat and mass fluxes surrounding the greenhouse. A two-minute time step is used to calculate the dynamic process and recalculate all state parameters such as for example the greenhouse temperature. The greenhouse air temperature, canopy temperature, relative humidity, transpiration etc. are all calculated for a specific time period. All the resources used, such as water, energy and carbon dioxide are calculated. The production is also modelled in terms of dry matter production which can be translated into fresh produce. The models have been validated with experimental data over the years and has been extended describing the economic implications (Vanthoor, 2011).

For the simulation studies climatic data from Aguascalientes were provided by La Huerta. The data described the ambient conditions in terms of temperature, relative humidity and radiation, the data originated from 2010-2011.

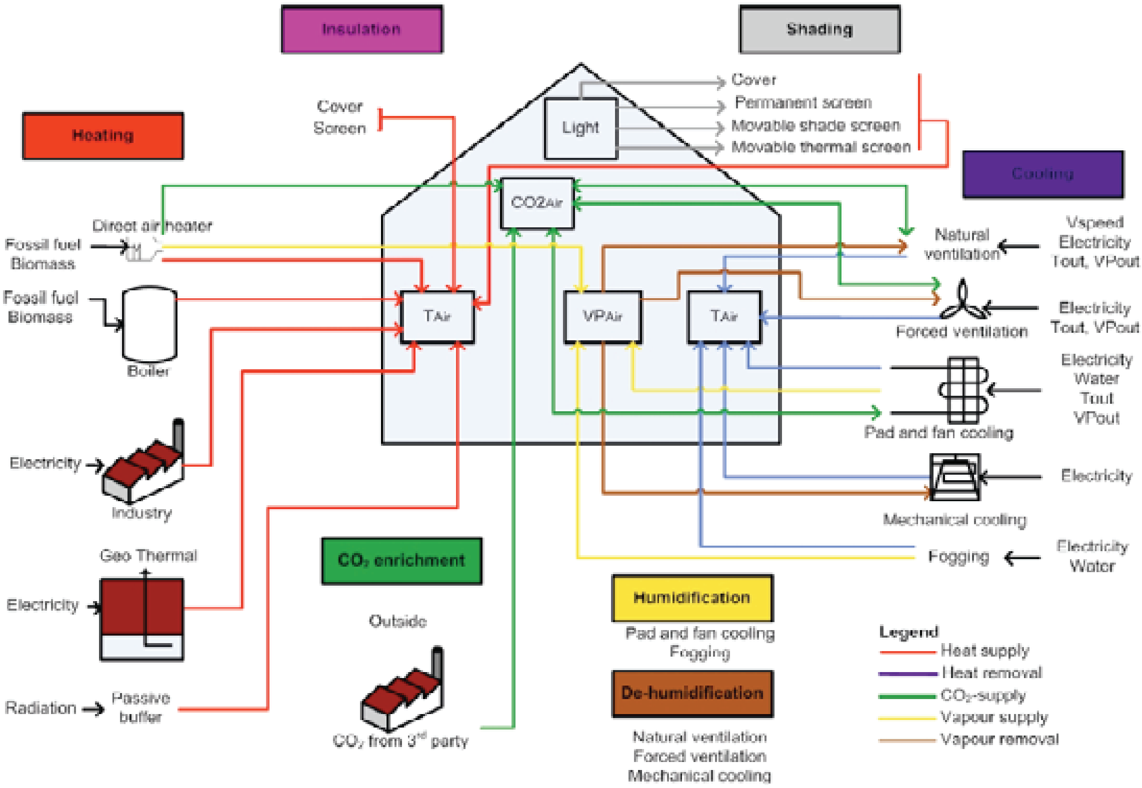


Figure 5. Visualization of the dominant fluxes and states used in the dynamic simulation model.

2.4 Scenarios

2.4.1 Technology levels

An arbitrary classification of the technology level of the protecting structure and the internal components is used in Mexico: “low-tech”, “medium-tech” and “high-tech”. Keeping the limitations of this classification in mind[1], we here use a set of definitions that help to organize the scenario studies. The low-tech greenhouse is described as a naturally ventilated greenhouse where the crop is grown in the soil. The mediumd-tech greenhouse is more sophisticated in terms of climate control and growing strategy. The high-tech greenhouse is a closed greenhouse where all parameters are controlled optimally.

1 There are a number of problems with this classification (García Victoria *et al.* 2011):
Definitions of the three categories vary, and different users apply different interpretations. For example, a mid-tech level in The Netherlands is mostly considered high-tech in Mexico.
Classifications suggest that high-tech is the highest possible technology and can not be improved upon. However, horticultural developments are very dynamic, and there is always room for improvement. For example AMPHAC (Asociación mexicana de horticultura protegida) prefers to speak of best-fit technology.
A fundamental problem of classifying is the simplification of transition processes. A construction of greenhouses, with an installation inside, and with a particular cultivation system gradually changes in stepwise process in which elements are replaced by more advanced ones.
For a fair judgement, it is required to present a reasonably detailed description of a greenhouse farm.

Figure 6. Cooling installation outside and inside the greenhouse needed to remove the heat in a closed greenhouse. This type of greenhouse is considered high-tech.

2.4.2 Scenarios

Table 1. shows the alternative greenhouse designs which have been studied using the model. The low-tech greenhouse is a simple plastic greenhouse where only the windows and irrigation are controlled automatically. The medium-tech greenhouses include heating. More instruments are added to this design to determine the effect on energy use, water use and production. The high-tech greenhouse is considered completely controlled in terms of climate without artificial lighting.

Table 1. Overview of scenarios considered.

Greenhouse character	Technology level						
	Low	Medium 1	Medium 2	Medium 3	Medium 4	Medium 5	High
Covering	P	P	P	P	P	G	D
Heating	N	Y,H	Y,H	Y,P	Y,P	Y,P	Y,P
Cooling	V	V	V	V	E	V	M
Thermal screens	N	N	Y	N	N	N	Y
Substrate	G	S	S	S	S	R	R
CO_2 enrichment	N	N	N	Y	N	Y	Y

Legend:
Covering: P=Plastic, G= Glass, D=Diffuse Glass
Heating: Yes/No H: air heaters in the greenhouse, P: heating pipes in the greenhouse
Cooling: V=Ventilation, E=evaporative cooling, M=mechanical cooling
Thermal screens: Yes/No
Substrate: G=soil ('Ground'), S=Soilless, R=Soilless with re-use of water
CO_2 enrichment: Yes/ No

When heating is done by air heaters (H) directly heating the greenhouse air, the carbon dioxide level in the greenhouse is increased. However, because the heat demand is mainly in dark periods, itwill not contribute substantially to production. Alternatively the heating is done by hot water (P) that is heated up by a gas-boiler, where the heat is distributed by a pipe network in the greenhouse.

This system allows accurate carbon dioxide enrichment by using the flue gasses from the boiler. The flue gasses have to been clean enough to prevent them from causing damage to the crop. The burner has to be regulated well to avoid problems. A heat storage buffer is needed to store the heat produced during the day, when the gas is burned for the carbon dioxide enrichment. The stored heat can be used during night time to heat the greenhouse. This type of enrichment is applied in the calculations using a heat storage buffer with a size of 150 m^3 per hectare of greenhouse.

An alternative is to use pure carbon dioxide for enrichment. The economic feasibility of the application depends on the price of the CO_2 and the price of the production. Since the price of CO_2 is not exactly know this option was not considered in this study.

When misting is applied for evaporatieve cooling (E, Medium 4) the production period can be extended as it reduces the greenhouse air temperature during the summer months. For the calculations it is assumed that in this case the crop is removed begin of May and directly replanted. In all other scenarios, crops are planted in August.

The scenario Medium 1 describes the current setup of La Huerta. Scenario Medium 3 describes the newly constructed greenhouse.

2.4.3 Outdoor climate

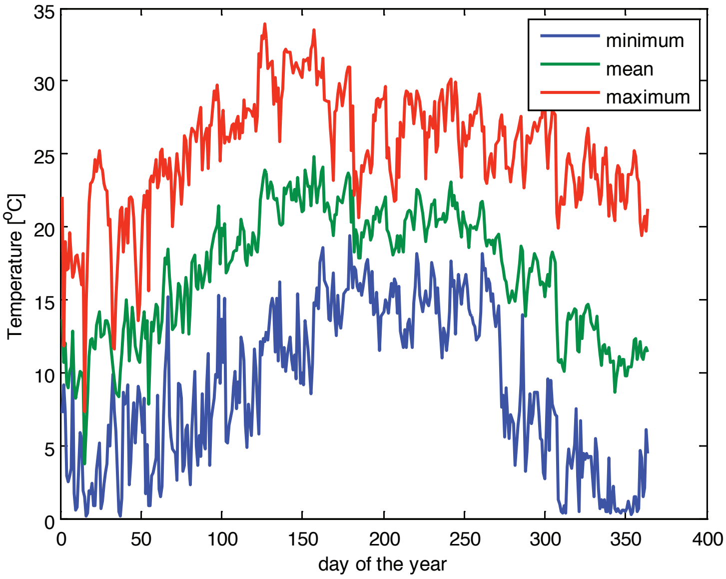


Figure 7. Temperature at Aguascalientes over the year 2010

The mean daily outside temperature and the maximum and minimum daily temperature for Aguascalientes in 2010 is shown in Figure 7. Optimal mean daily temperatures for tomato production are approximately between 18 and 22 °C. Negative effects on production can be found when the mean daily temperature drops below 12 °C or rises above 27 °C. Therefore, heating is needed during wintertime and little cooling is needed in summertime.

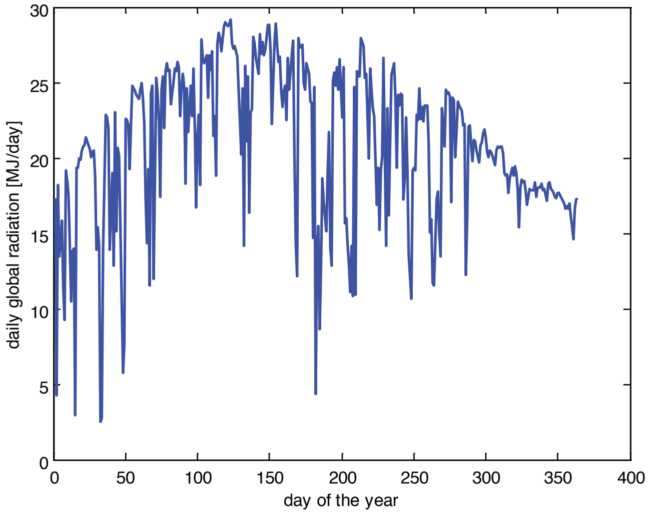


Figure 8. Daily global radiation over the year

The overall annual global radiation is 7.5 GJ according to the measurements. This is almost twice the amount of solar radiation compared to The Netherlands, which means that the potential production is much higher than in The Netherlands (although not the double, as other climate factors might be limiting).

2.4.4 Greenhouse climate

The temperature in the greenhouse is an important parameter for the production. Figure 9. shows the temperature in a unheated low-tech greenhouse (L) with year-round production. The red lines give the temperature limits on an hourly base and the green lines give the temperature limits on a daily base. If the temperature is kept within these limits the climate is optimal for tomato cultivation. From the Figure it can be concluded that with heating a very good climate can be created yearround.

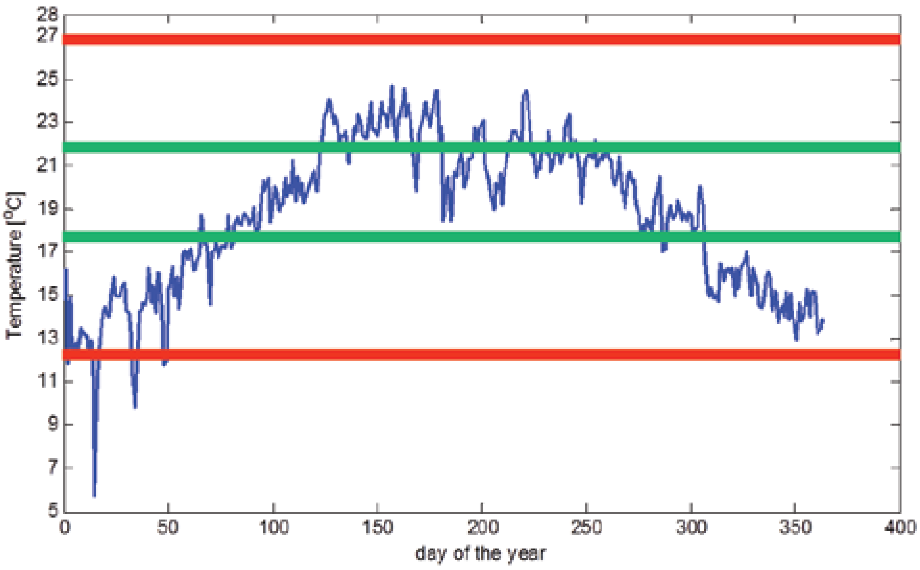


Figure 9. Daily mean temperature in the low tech greenhouse with year-round production.

Figure 10. shows the maximum, minimum and average daily temperature in a heated greenhouse (M1). Apart from the maximum temperature which tends to increase above 30 °C during the day, the climate over the year is good. The major difference with an unheated greenhouse lies in the higher daily average temperature in winter, when heating is applied. The average daily temperature in summer, when heating is not applied, is approximately the same as in an unheated greenhouse.

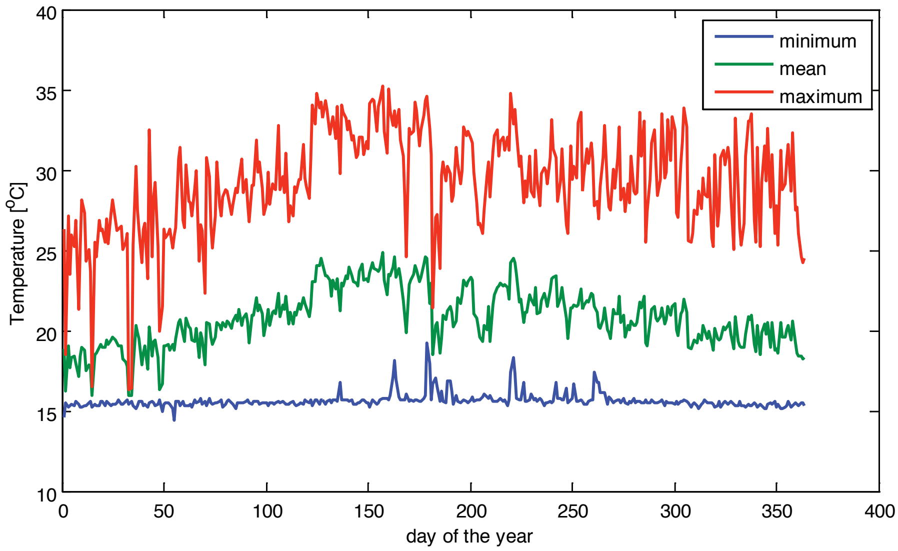


Figure 10. Minimum, maximum and mean daily temperature over the year in the Medium 1 greenhouse design with year-round production

2.4.5 Resources

The climatic setpoints used are similar for all scenarios in order to make a proper comparison. Heating is used when the temperature drops below 16 °C. Ventilation windows open above 18 °C and this setpoint is raised lineairly by 6 °C for 100 to 800 W/m^2 of solar radiation outside.

Table 2. Summary of variable costs for resources.

Resources	Unit*	Price	source
natural gas	$ kg^{-1}	11.49	La Huerta
electricity	$ kWh^{-1}	0.37	La Huerta
CO_2 pure	$ kg^{-1}	3.27	Estimate
Plant material	$ plant^{-1}	15.69	La Huerta
labour costs crop	$ h^{-1}	36.27	La Huerta
crop protection	$ m^{-2}	16.34	Estimate
crop nutrition closed cycle	$ kg tomato	0.92	La Huerta
water (water system, transpiration, fogging)	$ m^{-3}	0.64	La Huerta
substrate	$ m^{-2}	21.24	KWIN**
plastic film, wires, clips	$ m^{-2}	8.17	KWIN**

*: prices are given in Mexican pesos
**: KWIN 2010, Vermeulen et al.

2.4.6 Market

Products from La Huerta are sold on the domestic market as well as exported to the USA. The export prices are higher than domestic prices, however, the quality has to be higher as well. The prices used for the economic analysis are listed in Annex 2 and are based on the information provided by La Huerta.

2.4.7 Production and Resource Use Efficiency

Table 3. shows the main characterics for the operation, production, water use and energy use. In order to make a comparison between the different scenarios the efficiency use of water and energy is given.

Computed production under heated medium-tech conditions is substantially higher than under un-heated low-tech conditions, and computed production under high-tech conditions is substantially higher than under mid-tech conditions. The difference between production under the best mid-tech and high-tech conditions is caused by the use of diffuse glass, which realized a better light spectrum, and the fact that the climate can be controlled optimally, especially regarding the carbon dioxide concentration. Also intermediate planting is assumed in this scenario which makes yearround production possible. The calculated production under M1 (50.7 kg m^{-2}) is slightly higher than in practice (48 kg m^{-2}) since the calculations assume ideal conditions (no diseases, etc.). Carbon dioxide enrichment using the flue gasses from the boiler has a very positive effect on the production (M3, M5, H). The production increase due to evaporative cooling (M4) is limited, since extremely high temperatures do not occur at this location which makes the evaporative cooling less functional. Evaporative cooling therefore is not profitable for this region.

Table 3. Summary of production and resource use efficiencies. Results are graphically presented in Annex 4.

Greenhouse character	Dimension	Technology level						
		Low	Medium 1	Medium 2	Medium 3	Medium 4	Medium 5	High
Fresh tomato production	kg m^{-2} y^{-1}	21.6	50.7	49.3	70.3	53.6	67.5	134.5
Water use	M^3 m^{-2} y^{-1}	3	2	2	2	2	1.3	0.6
Energy use	MJ m^{-2} y^{-1}	43	762	604	922	768	778	3465
Water use efficiency	kg m^{-3}	7.2	25.3	24.7	35.2	21.4	51.9	168.2
Energy use efficiency	kg GJ^{-1}	505	67	82	76	70	87	39

The water use is directly related to the use of substrate and the application of recirculation of drain.

Energy use is relatively low under low-tech conditions, and much higher under mid-tech conditions where energy is required for heating and for pumps to allow water recirculation. Mechanical cooling under high-tech conditions increases the energy use.

Energy use is expressed in MJ m^{-2} y-1, so the heat source can be alternated. Geothermal heat which is available in the region of La Huerta can also be utilized. Whether this heating source is a good alternative depends on numerous factors such as the temperature of the water from the well, the depth of the well, the method of discharging the return water, and minerals in the water. More information is needed to determine the economic potential of this heat source.

On the whole, water use efficiency increases with the level of technology. Per m3 of water, the highest amount of produce is generated under high-tech conditions. This is mainly explained by the use of soilless cultivation systems and the recirculation of the water.

Energy use efficiency shows a reverse pattern: it decreases as the technology level increases. The extra production does not keep pace with the extra amount of energy.

2.4.8 Economic analysis

Total investment costs increase with the technology level, from 551 Mex. \$ m^{-2} for a low-tech greenhouse to 3759 Mex. \$ m^{-2} for a high-tech greenhouse. Taking into account interest rates and depreciation, the annual investment or installation costs range from 77 Mex. \$ m^{-2} y^{-1} to 529 Mex. \$ m^{-2} y^{-1}, respectively.

Variable costs vary between 126 Mex. \$ m^{-2} y^{-1} and 712 Mex. \$ m^{-2} y^{-1}, respectively, for a low-tech and a high-tech greenhouse. Labour costs are associated with production level: for that reason, M3 has higher labour costs than for example M2.

Table 4. Summary of economic analysis. Results are graphically presented in Annex 4.

Greenhouse character	Dimension	Technology level						
		Low	Medium 1	Medium 2	Medium 3	Medium 4	Medium 5	High
Investment costs	**Mex. \$ m^{-2}**	**551**	**715**	**780**	**934**	**896**	**1008**	**3759**
Greenhouse construction and covering	Mex. \$ m^{-2} y^{-1}	16	36	36	36	36	36	74
Other installation costs**	Mex. \$ m^{-2} y^{-1}	12	16	38	47	41	57	396
Additional installation costs***	Mex. \$ m^{-2} y^{-1}	49	59	59	59	59	59	118
Total installation costs****	**Mex. \$ m^{-2} y^{-1}**	**77**	**110**	**132**	**142**	**136**	**151**	**529**
Energy and CO_2	Mex. \$ m^{-2} y^{-1}	2	151	115	172	162	172	340
Labour	Mex. \$ m^{-2} y^{-1}	36	85	83	118	90	118	225
Water, nutrients and recirculation	Mex. \$ m^{-2} y^{-1}	21	48	46	50	39	33	62
Others*	Mex. \$ m^{-2} y^{-1}	67	77	77	74	82	74	85
Total variable costs	**Mex. \$ m^{-2} y^{-1}**	**126**	**361**	**321**	**413**	**372**	**397**	**712**
Total income crop	**Mex. \$ m^{-2} y^{-1}**	**275**	**708**	**690**	**1007**	**716**	**1007**	**1796**
Net income	**Mex. \$ m^{-2} y^{-1}**	**71**	**237**	**236**	**451**	**206**	**458**	**554**
Return on investment	**year**	**5.3**	**2.8**	**3.0**	**1.9**	**3.5**	**1.9**	**3.5**

*: chemicals, substrate, packaging, etc.
**: heating, CO_2, climate control, screening, etc.
***: transport, lifts, packaging area, store, etc
****: incl. depreciation, maintenance, interest

The computed income results from the computed production and the market prices (we used the 2011 values). Extending the growing period (M4) has only a limited impact on the production, and only results in a slightly higher net income due to the low prices in the summer period. If prices would be higher in the summer period, extending the growing period is a good change in management strategy. For the high tech greenhouse it is assumed that all products are for the export market so the higher prices are considered in this case (Annex 2).

In the current greenhouse (M1) according to the model calculations an annual net income of 237 Mex. $ per square meter of greenhouse can be reached. The new greenhouse (M3) has a higher annual net income of 451 Mex. $ per square meter of greenhouse, and is therefore a good investment.

The pay-back time of the investments is a different economic indicator. It appears that the relatively low investments in a low-tech greenhouse nevertheless require more than five years to be earned back, due to the low production levels. The investments in the current (M1) greenhouse are earned in less than three years, while the investments in the new (M3) greenhouse are earned in less than two years. Therefore, it appears to have been a wise company strategy of La Huerta to expand the farm at a higher technology level.

Investment in a glass cover together with a water re-use installation (M5 scenario) instead of a plastic cover results in the same net income as the M3 scenario. The glass cover needs a higher initial investment but it will last for many years resulting in a low depreciation. Re-use of water saves on water and nutrients which also compensates for the higher investment costs.

2.4.9 Sustainability

The optimal design in terms of sustainability depends on the weighting factors used on the factors listed in Table 5.

Water use per m^2 greenhouse decreases with technology level, and as the production per m^2 greenhouse increases with technology level, the water use efficiency is highest for higher technology levels. This is an important consideration, given the fact that water resources are limited in the state of Aguascalientes.

The production increase per m^2 greenhouse causes an increased use *by the crop*, in absolute terms, of nutrients per m^2 greenhouse. However, as long as water and nutrients are drained to the outside environment, any system can not be considered really sustainable. Only recirculation systems (M5 and H) are environmentally sustainable. The costs of nutrient application are determined by the annual amount of nutrients that are applied to the system, and therefore by the amounts of nutrients taken up by the crop (an inevitable cost that can not be avoided), and drained to the environment (a cost that can be avoided).

It is worth to stress that the option “soilles cultivation with water re-use” has been considered only in the scenarios M5 and H to limit the number of scenarios. However, tecnically this option is possible, and presumably also economically feasible, in all other considered “soilless” scenarios, so all scenarios with the exception of “Low”, where recirculation of drainwater is not possible as cultivation takes place in the soil. The recirculation of drainage w ter in soilless cultures increases the sustainability of the greenhouse in two ways: 1) enabling a higher water use efficiency, and 2) reducing the environmental impact by avoiding nutrient leaching and pesticide leaching (through lxyviates) to the soil and the groundwater.

The plastic greenhouses are graded less sustainable in terms of construction since the durability of plastic is limited to a maximum of three years. Plastic covers mustbe replaced every three years. But in areas with frequent strong winds, plastic covers are often blown away by winds and need frequent replacement anyway. Plastic recycling is possible and contributes to reduce the environmental impact of plastic covers. A glass cover has a life time of more than 20 years, and therefore, scores lower on environmental impact in all studies impact categories than plastic covers in LCA (Torrellas *et al.* 2011).

Pesticide use may reduce both product quality (presence of residues, which can be an important market burden) and product quantity (due to the phytotoxic effects of the chemicals), so avoiding using chemicals is important. A well constructed greenhouse limits the amount of insects that enters, and is therefore an important crop protection measure: it is the first step to limit insect pressure. Furthermore biological control should be applied to control the pests and diseases.

Energy use is relatively low under low-tech conditions, and much higher under mid-tech conditions where energy is required for heating and for pumps to drive the water recirculation. Mechanical cooling under high-tech conditions increases the energy use. Energy use efficiency shows a reverse pattern: it decreases as the technology level increases. The amount of extra produce does not keep pace with the extra amount of energy.

Table 5. Sustainability factors of the various greenhouse scenarios.

	Low	M1	M2	M3	M4	M5	H
Water use	- -	-	-	-	-	+	++
Nutrient use	- -	-	-	-	-	++	++
Construction	- -	-	-	-	-	+	+
Pesticides	- -	-	-	-	0	0	++
Energy	++	0	0	0	0	0	–

2.4.10 Conclusions

Production levels
The climate in Aguascalientes is suitable for horticultural production under protected conditions, however, heating in winter time, when temperatures are low, considerably improves the production level. A further increase in production is realized through the day time use of CO_2 flue gasses from the heating system. Diffuse glass that realizes a better light spectrum and thermal screens that realize higher temperatures in winter time are further steps to increase yield.

Economic sustainability
The use of CO_2 flue gasses from the heating system leads to higher variable costs, however, the balance with the increased production is such that these systems have the shortest pay-back time (M3 and M5; 1.9 years). If CO_2 flue gasses are used in combination with other high-tech options (H), then the pay-back time increases to 3.5 years. The low-tech option has the longest pay-back time (5 years). In a way, this reflects the law of diminishing returns.

The pay-back time is not the only criterion that is relevant to a grower. The investments needed and the options to generate or lend these funds can very well be the determining factor; if investment funds are difficult to obtain, the low-tech scenario might be the best option.

The net income may be the most relevant variable for other growers, in which case the high-tech scenario (H) is the most attractive.

In terms of pay-back time, the mid-tech greenhouse that is currently under construction at La Huerta (M3), is an optimal solution. The reasons for this are the low use of relatively expensive energy and the low price of water.

Water use efficiency
Water use does not vary much in absolute terms among the technical alternatives, but as the production does, the water use efficiency strongly increases with increasing technology level. Application of soilless cultivation increases sustainability in terms of water, and also in terms of nutrient use. This can be further optimised by re-use of water.

Energy use effciency
The energy use efficiency decreases with increasing technololgy level, due to the relatively strong increased use of energy in absolute terms. The sustainability in terms of energy will be improved if the use of energy from geothermal sources is possible.

3 Workshop

The results of the adaptive greenhouse study were presented and discussed with a group of growers, suppliers and representatives from the public sector of Aguascalientes, during a workshop with the title ‘A sustainable and economically feasible greenhouse for Mexico’. The workshop was held at November 29^{th}, 2012, at La Huerta farm in Aguascalientes.

The objectives of the workshop were:

1. Increase awareness of sustainability issues and technical options
2. Discuss sustainability objectives of Mexican horticulture
3. Discuss implications for greenhouses

The workshop was organized by Mr. Juan Pablo Mora Mora from La Huerta farm, and Mr. Anne Elings from Wageningen UR Greenhouse Horticulture.

3.1 Workshop programme

Table 6. Programme of the workshop ‘A sustainable and economically feasible greenhouse for Mexico’.

Time	Item	speaker
9:00	Welcome	Fernanda Bastidas Peregrina, La Huerta
9:05	Introduction to the farm	Fernanda Bastidas Peregrina, La Huerta
9:30	Sustainability in, future of Mexican protected horticulture	Jorge A. Narvaez - Minister of Rural Development and Agrobusiness of the State of Aguascalientes
10:30	Greenhouse design	Anne Elings, Wageningen UR Greenhouse Horticulture
11:15	Available technology to reach sustainability	Bram Vanthoor, HortiMax
12:00	Tour around the farm	Roberto Farfán, La Huerta
13:00	Lunch	
14:30	General discussion	Anne Elings, Wageningen UR Greenhouse Horticulture Roberto Farfán, Juan Pablo Mora, La Huerta
16:00	Closure	Anne Elings, Wageningen UR Greenhouse Horticulture

3.2 Introductions

3.2.1 Jorge Narvaez - Minister of Rural Development Agrobusiness of the State of Aguascalientes

Mr. Jorge A. Narvaez, Minister of Rural Development and Agrobusiness of the State of Aguascalientes made a great effort to give an introduction at the workshop. He presented his vision of a sustainable development of the horticultural sector in Aguascalientes.

His vision is summarized as:

- Integrate developments at a high level
- Make more efficient use of resources, e.g., water
- Pay attention to food safety and alternative sources of energy

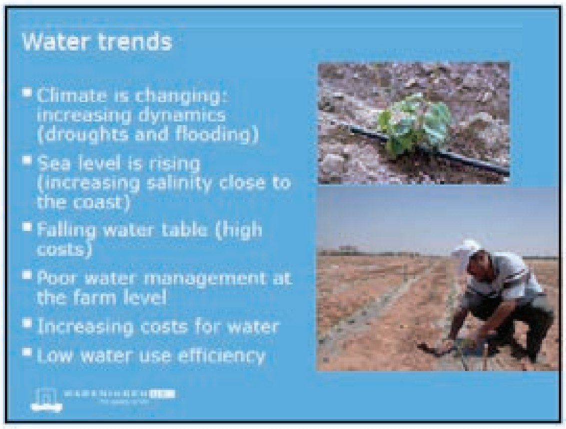
- Reduce production costs
- Adapt available knowledge, e.g., knowledge available from The Netherlands
- Waiting is not an option, as it will lead to a backlog
- Make a good analysis of the entire sector in Aguascalientes, balance all factors, and take clear decisions.
- Organize the sector, and cluster greenhouses
- Knowledge is fundamental; invest in universities, research institutions; ranges from communities to centres of excellence.

The presence of Mr. Jorge A. Narvaez was very much appreciated.

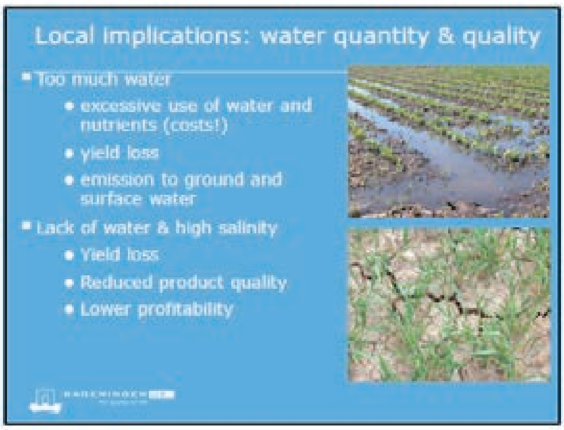
3.2.2 Dr. Anne Elings - Wageningen UR Greenhouse Horticulture

Dr. Anne Elings is scientist at Wageningen UR Greenhouse Horticulture and presented the results of the adaptive greenhouse study.

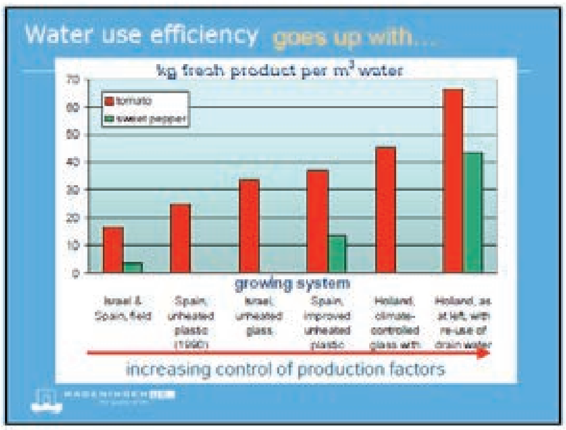
Greenhouses in Mexico – The La Huerta case
Anne Elings, Jouke Campen & Juan Pablo Mora Mora



Water trends
Climate is changing: increasing dynamics (droughts and flooding)
Sea level is rising (increasing salinity close to the coast)
Falling water table (high costs)
Poor water management at the farm level
Increasing costs for water
Low water use efficiency

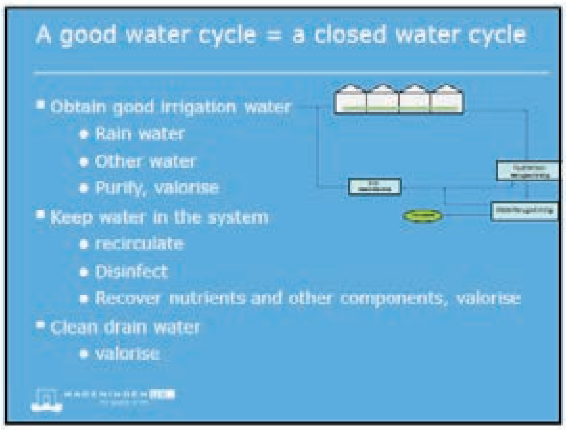


Local implications: water quantity & quality
Too much water
excessive use of water and nutrients (costs!)
yield loss
emission to ground and surface water
Lack of water & high salinity
Yield loss
Reduced product quality
Lower profitability



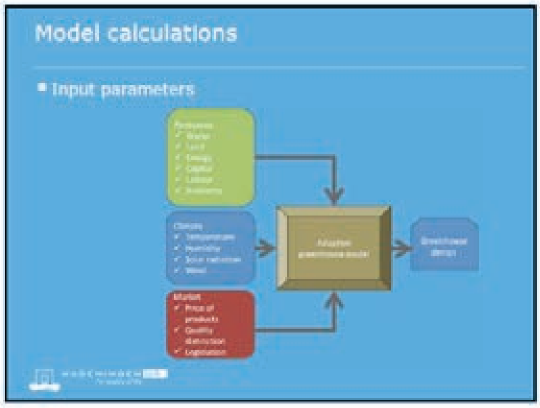
Water use efficiency goes up with...
kg fresh product per m³ water
tomato
sweet pepper
70
60
50
40
30
20
10
0
growing system
Israel & Spain, field
Spain, unheated plastic (1990)
Israel, unheated glass
Spain, improved unheated plastic
Holland, climate-controlled glass with
Holland, as at left, with re-use of drain water
increasing control of production factors

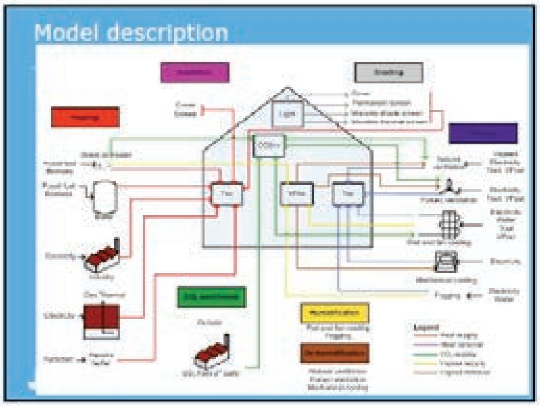
Water Use Efficiency (WUE)
From soil to substrate & from open to covered



A good water cycle = a closed water cycle
Obtain good irrigation water
Rain water
Other water
Purify, valorise
Keep water in the system
recirculate
Disinfect
Recover nutrients and other components, valorise
Clean drain water
valorise


Adaptive greenhouse simulations
Determination of the most sustainable and economical feasible greenhouse for La Huerta


Model calculations
Input parameters


Model description


Low tech greenhouse: naturally ventilated greenhouse
Naturally ventilated
Soil bound growing
Low production
Low quality


Mid tech greenhouse: more technology
Plastic covering
Controlled ventilation
Soilless cultivation
Variations applied:
Thermal screen application
Carbon dioxide enrichment
Reuse of drain water
Evaporative cooling


High tech greenhouse: Closed greenhouse (AC)
Minimum or no air exchange with outside air
Cooling system
Air treatment unit
Fogging
CO2 enrichment
Cover without vents

Scenarios

Parameter	L	M1	M2	M3	M4	M5	H
Covering	P	P	P	P	P	P	D
Heating	N	Y, H	Y,H	Y,P	Y,P	Y,P	Y,P
Cooling	V	V	V	V	E	V	M
Thermal screens	N	N	Y	N	N	N	Y
Substrate	G	S	S	S	S	R	R
CO_2 enrichment	N	N	N	Y	N	Y	Y

- Covering, P=Plastic, G= Glass, D=Diffuse Glass
- Heating Yes/No, H: air heaters in the greenhouse, P: heating pipes in the greenhouse
- Cooling, V=Ventilation, E=evaporative cooling, M=mechanical cooling
- Thermal screens, Yes/No
- Substrate, G=ground, S=Soilless, R=Soilless with reuse of water
- CO_2 enrichment, Yes/ No

Comparison of alternatives

Greenhouse character	Dimension	L	M 1	M 2	M 3	M 4	M 5	H
Water use	$m^3\ m^{-2}\ y^{-1}$	3	2	2	2	3	1.5	0.8
Energy use	$MJ\ m^{-2}\ y^{-1}$	43	762	604	922	950	857	3465
Fresh tomato production	$kg\ m^{-2}\ y^{-1}$	21.6	50.7	49.3	70.3	53.6	70.3	134.5
Water use efficiency	$kg\ m^{-3}$	7.2	25.3	24.7	35.2	17.9	46.9	168.2
Energy use efficiency	$kg\ GJ^{-1}$	505	67	82	76	56	73	39

Economic Analysis

- Assumptions for operational costs

Resources	Price	source
natural gas [$/kg]	11.49	Juan Mora
electricity [$/kWh]	0.37	Juan Mora
CO_2 [$/kg] pure	3.27	Estimate
Plant material [$/plant]	15.69	Juan Mora
labour costs crop [$/h]	36.27	Juan Mora
crop protection [$/m²]	16.34	Estimate
crop nutrition closed cycle [$/kg tomato]	0.92	Juan Mora
water [$/m³] (water system, transpiration, fogging)	0.64	Juan Mora
substrate	21.24	KWIN
plastic film, wires, clips	8.17	KWIN

Economic analysis

Greenhouse character	Dimension	Low	Medium 1	Medium 2	Medium 3	Medium 4	Medium 5	High
Return on investment	year	5.3	2.8	3.0	1.9	3.5	1.9	3.5
Investment costs	Mex. $ m^{-2}	551	715	700	934	896	1000	1759
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Energy and CO_2	Mex. $ $m^{-2}\ y^{-1}$	2	151	115	172	162	172	340
Labour	Mex. $ $m^{-2}\ y^{-1}$	35	85	83	118	90	118	225
Water, nutrients and recirculation	Mex. $ $m^{-2}\ y^{-1}$	21	48	46	50	39	33	62
Others (chemicals, substrate, packaging, etc.)	Mex. $ $m^{-2}\ y^{-1}$	67	77	77	74	82	74	85
Total variable costs	Mex. $ $m^{-2}\ y^{-1}$	126	361	321	413	372	397	712
Greenhouse construction and covering	Mex. $ $m^{-2}\ y^{-1}$	18	36	36	36	36	36	74
Other installation costs (heating, CO_2, climate control, screening, etc.)	Mex. $ $m^{-2}\ y^{-1}$	12	16	[illegible]	47	41	57	396
Additional installation costs (transport, ..., packaging area, stores etc.)	Mex. $ $m^{-2}\ y^{-1}$	49	59	59	59	59	59	118
Total installation costs incl. depreciation, maintenance, interest	Mex. $ $m^{-2}\ y^{-1}$	77	110	132	142	136	151	529
Net income	Mex. $ $m^{-2}\ y^{-1}$	71	237	230	451	205	458	554

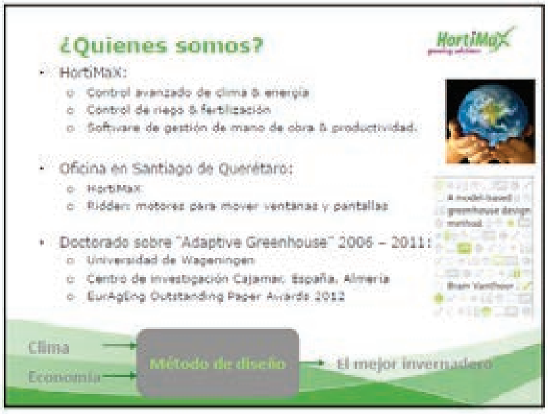
Summary

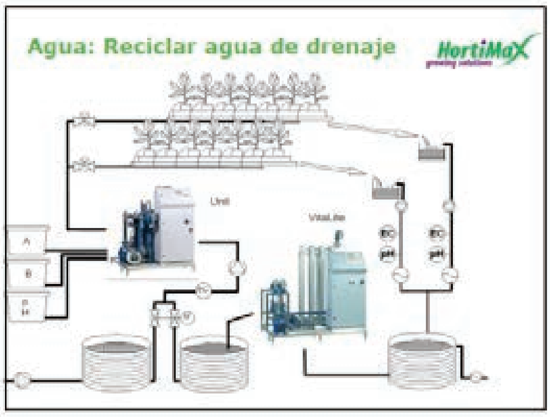
- With increasing technology level
  - Higher investments
  - Higher production
  - Higher net income
  - Higher resource-use efficiency
- Low-tech:
  - Longest return on investment
- Energy use increases with cooling & heating
- How does this fit in your company strategy?
- How does this fit in regional developments?

Muchas gracias

3.2.3 Dr. Bram Vanthoor - HortiMax

Dr. Bram Vanthoor is representative of HortiMax B.V, and kindly elaborated on the technical possibilities to reach higher technology levels in protected cultivation.



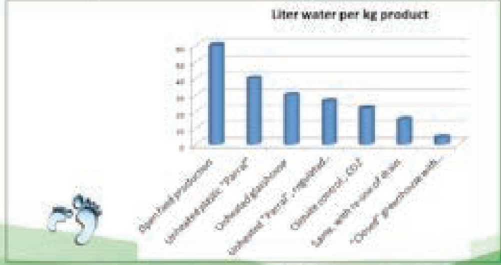


Agua: Reciclar agua de drenaje

- Ahorra 30% en fertilizantes
  - 10.000 USD/Ha/Año
- Tecnología muy confiable:
  - Rijk Zwaan Holanda

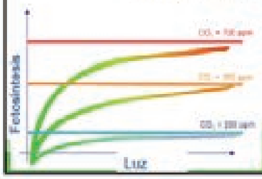
Agua: Más tecnología

- ¡Mas tecnología resulta en menos consumo de agua!



Energía: Aprovechar el CO_2

- Combustion: combustible→ energía y CO_2
- Aprovechar todo el CO_2: Calefacción con caldera y buffer de agua caliente
  - Día:
    - Caldera encendido, calor al buffer. CO_2 al invernadero
  - Noche:
    - Caldera apagado, calor del buffer al invernadero



Energía: Invernaderos aislados

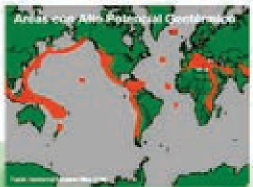
- Algunos números holandeses

Cubierta	Uso de energía (m³ gas/m²/año)	%
Una sola capa	53	100 %
Una sola capa con baja emisión	48	91%
Una sola capa con pantalla	40	75%
Doble capa	40	75%
Doble capa con pantalla	33	62%

Fuente: Universidad de Wageningen

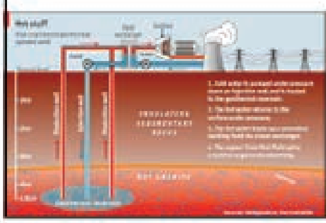
Energía: Geotérmica

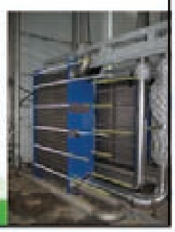
- ¿Aguascalientes?
- México tiene mucha potencia de Geotérmica
- Invernaderos:
  - Holanda: Agua de 65 centigrados a una profundidad de 2300 metros
  - México: ¡Agua de 95 centigrados o más a nivel del suelo!



Energía: Geotérmica

- Proyecto Duijvestijn, Holanda
  - Agua de 65 centigrados a una profundidad de 2300 metros
- Inversión alta pero costos de operación muy bajos
- Inversión en México es mas baja y por eso muchos oportunidades
- ¿CO_2?





Energía: Calor del 'vecino'

- Calor y CO_2 son subproductos de la industria, por ejemplo:
  - Central termoeléctrica
  - Fabricación de fertilizantes
- Podríamos reusarlos en los invernaderos:
  - El Sauz, Pedro Escobedo (5 Ha) y Agrogen, Querétaro (13 Ha)

Energía

- Otras opciones:
  - Diferencias de temperaturas entre día y noche más grandes
  - Variedades que aguanta temperaturas más bajas
  - Ubicación del invernadero con menor demanda de calor

Resumen

- Más sostenible no significa siempre más rentable
- !Pero muchas veces si!
  - Reciclar agua de drenaje
  - Aprovechar calor y CO_2
  - Aislar invernaderos
  - ....
- Inversión a veces alta pero tiempo de retorno corto

Los pasos adecuados

1. Elegir una ubicación adecuado
   - Clima, agua, electricidad, combustible, cerca del mercado
2. Elegir la estructura del invernadero adecuado
   - Ventilación
   - Transmisividad de luz
   - Aislado
   - ......
3. Usar tecnología para mejorar rendimiento y/o sostenibilidad

Gracias por su atención

Dr. Bram Vanthoor

Santiago de Queretaro - 442 106 3220

bvanthoor@hortimax.com

www.hortimax.com.mx

Resumen

- Agua y fertilizantes:
  - Recoger el agua de lluvia
  - Reciclar agua de drenaje
- Calefacción y CO2
  - Sistema de buffer y caldera
  - Invernaderos mejor aislados
    - Doble plástico / pantalla térmica
  - Geotérmica
  - Calor del 'vecino' termo eléctrica
  - Diferencias de temperatura entre día y noche más grandes
  - Variedades que aguanta temperaturas mas bajas
  - Ubicación del invernadero con menor demanda de calor

3.3 Farm tour

Figure 11. Inside the existing greenhouse.

Figure 12. Top ventilation of the existing greenhouse.

Figure 13. In front of the new greenhouses under construction.

3.4 General discussion

Apart from discussion during the various presentations, the workshop was concluded by an assessment of the perceived positive and negative aspects of technological advancement in protected cultivation. The participants were divided in three groups, who were given 45 minutes to formulate their points (Figure 14, Table 7.). The summaries of their discussions were plenary presented.

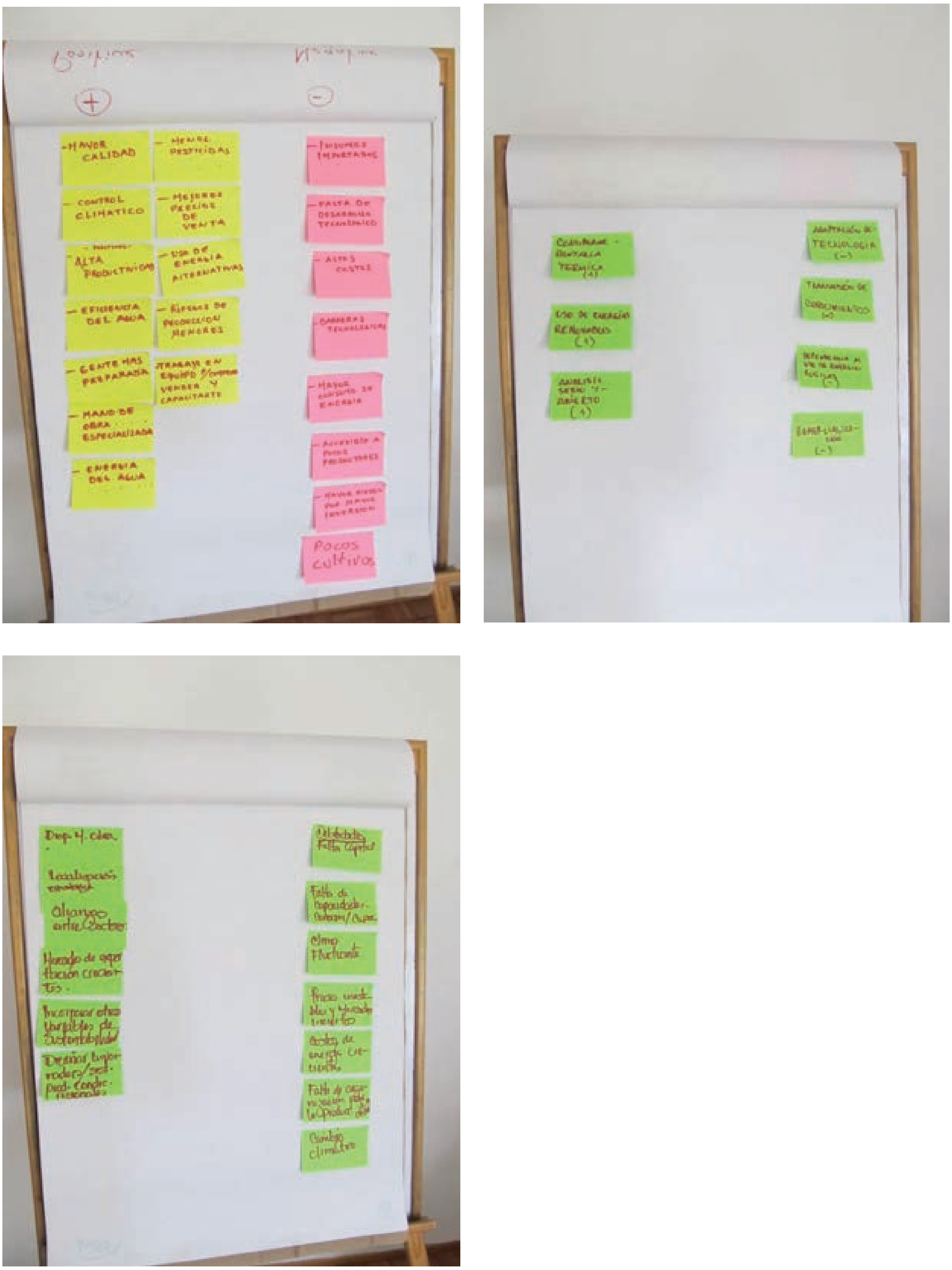


Figure 14. Positive and negative aspects of technological development in protected cultivation.

The participants provided a broad range of positive and negative aspects of increased technological systems (Table 7.). It was not debated whether the points brought forward were accurate, only perceived, can easily be addressed, etc. Their importance lies in the fact that the issues raised must be built upon (the positive points) or dealt with (the negative points) in transition processes. Positive points offer important building blocks for transition. If a negative point made is valid, then a solution must be found, if it concerns only a perceived problem then an awareness activity must be organized, and if an easy solution to a problem exists, then naturally this solution must be offered.

Table 7. Positive and negative aspects of an increased technology level, as mentioned during the workshop.

Positive aspects of an increased technology level		**Negative aspects of an increased technology level**	
Production			
Better product quality	Higher productivity	Few cultivars	
Strategic locations	Lower production risks		
Greenhouse			
Design of adapted greenhouses and regional production systems		(Insufficient) adaptation of technology	
Fair analysis		Imported goods	
Climate & Energy			
Climate control		Higher energy consumption, rising energy costs	
Use of alternative / renewable energy sources, e.g., hydro-electric energy		Dependency on fossil energy	
Consider energy screens		Fluctuating climate	
		Climate change	
Environment			
Water use efficiency			
Less chemical pesticides			
Inclusion of other sustainability factors			
Value chain			
Better product prices		High costs	Lack of capital
Alliances between actors		Lack of producers organizations	Unstable prices and inert markets
Increasing export market		Accessible for few producers	(Risks in terms of) commercialization
		High risks for large greenhouses	
Knowledge			
Better educated personnel		Lack of capacities and knowledge	
Specialized work		Lack of technological development	
Teamwork in purchase, selling and training		Technological barriers	
		(Lack of) knowledge transfer	

Production

Most importantly probably, production and product quality are expected to improve, and that through a better control of the production system, production risks are reduced.
If indeed the appropriate cultivars would not exist[2] then breeders and suppliers of planting materials must take action.

Greenhouse

An important concern is the fact that the technology is not sufficiently adapted. Examples and complaints indeed do exist of greenhouse designs that are not fully optimized on the basis of local environmental and economic conditions. Here lies an important role for the suppliers and knowledge providers. The workshop participants call for this and expect a fair analysis and optimum design of adapted greenhouses and regional production systems.
The fact that goods may have to be imported was raised as a negative aspect. This may be associated with for example the perceived higher costs, delivery time, or import procedures. The balance with quality and durability is important for suppliers (from, e.g., The Netherlands).

Climate and energy

The improved options for climate control were considered an important point, as this immediately reflects in increased production. However, there was a substantial concern that higher energy consumption with rising energy costs would affect the financial soundness of the farm. Alternative energy sources, such as hydro-electric energy or (for Aguascalientes) geothermal energy can offer solutions. Geothermy in Aguascalientes provides water of 46 °C. The location of the water sources is undeep, and therefore, the water is relatively easy to use.
Climate change and fluctuating climate conditions were considered negative points. These are probably valid points. It would be useful to assess the long-term climate changes in Mexico, and the variation in annual weather conditions, and to build a risk profile. On the basis of this, motivated decisions with regards to the greenhouse design can be taken.

Environment

Reduced water use and less pollution of the environment with chemicals were mentioned. These are indeed important advantages of good greenhouses and good crop management.

Value chain

A technological transition must generate sufficient income. More production generates more income, and better kg prices can be realized through for instance better product quality, more stable production, or contract farming. Alliances between chain actors and tapping new markets (e.g., export) are important for economic sustainability.
However, lack of capital, high costs, unstable or inert markets, lack of organization and high risks are all factors that negatively influence the income generation by farmers. It shows that transitions require much more than a technological step in greenhouse design, but also organizational re-design.

Knowledge

Protected cultivation is very knowledge-intensive. Designing and constructing the greenhouse is the easy part. Without skilled workers, placing an advanced greenhouse is futile. The participants were not entirely comfortable with this and identified a number of concerns. However, if the knowledge level is increased, then this results in a more skilled workforce that is of benefit to the entire sector. Knowledge actors, suppliers, growers themselves must all be involved in increasing the level of knowledge.

---

2 Which the authors of this report consider less likely.

Figure 15. Group picture (not all participant were present a the time of picture taking).

4 General discussion

This study has quantified the consequences for a number of sustainability indicators, viz. those for economy, water use and energy use, of transition to more advanced greenhouse systems, in particular for tomato cultivation under protected conditions at the La Huerta farm in Aguascalientes. Production (kg m^{-2} y^{-1}) increases, water use (m^3 m^{-2} y^{-1}) decreases, and energy use (J m^{-2} y^{-1}) increases. The general trend is that sustainability in terms of water (water use efficiency) increases with advancining technology, and that the sustainability in terms of energy (energy use efficiency) declines with advancing technology. Economic sustainabity, expressed in terms of net annual profit ($ m^{-2} y^{-1}) increases with increasing technology level, but is variable if expressed in terms of return of investment (y). The decision of La Huerta to move from a relatively low technological level (Medium 1 in this report) to a moderately high level (Medium 3 in this report) has been a correct one, if judged on the basis of return on investment.

Water is scarce in Aguascalientes, and therefore, water use and water use efficiency are important system characters. If the acreage of protected horticulture is going to increase, which might very well be the case if the considered Metropolitan Food Cluster is indeed implemented, then water resources are a major consideration. Drain water from a soilless culture system can be used for other purposes, such as outdoor horticulture, further increasing the water use efficiency. A problem, however, is that water is for free. As long as water is not charged, there is no economic incentive for the grower to improve the water use efficiency. As an alternative, certification and associated higher prices or better market positioning (a better water footprint) can stimulate a more responsible use of water.

Fossil energy is expensive, and its usage is not sustainable by default. For Aguascalientes the presence of geothermal energy could be exploited much better. For example in Iceland, and Turkey, geothermal energy is being used in greenhouse horticulture. In Hungary, it is by far the cheapest source of energy (Torrellas *et al.* 2011). Technically there should not be a serious limitation.

The study has taken La Huerta farm in Aguascalientes as an example. Greenhouse designs and sustainability indicators for other farms in other regions under different circumstances will be different. It is precisely for this reason that the adaptive greenhouse approach has been followed. Nevertheless, also under other situations resource use efficiency will increase with increasing technology level (Stanghellini, 2003).

The question is whether these developments can and should be initiated, as there are a number of other factors to be considered. Part of these were mentioned in the workshop:

- The entire production system must be altered to the different production system. Growth might be more vigourous, requiring a new management of vegetative vs. generative growth of the tomato plant. Different varieties might be needed. Water and nutrient management probably has to be revised given the different technical possibilities and altered crop requirements. The climate management has to be improved where possible.
- The more advanced greenhouse system itself must be sufficiently adapted, not only in its design to local circumstances but also in its use. This requires skilled workers for the operation which makes the investment higher, because training of management and staff is of extreme importance. Without good management and working skills, the advantages of a more advanced greenhouse can not be fully exploited.
- The funds for investments have to be available, either from own capital, or through affordable loans. For this reason, it might be wise to invite banks as active stakeholders in transition processes. Also unexpectedly increasing costs, unstable or inert markets, lack of organization are risk factors that can negatively influence the income generation by farmers. Wherever possible, actions should be undertaken in these areas.
- The variation in climate must be taken in consideration. We based ourselves for this indicative study on the data of only one year. Other years will be characterized by different weather conditions, different production levels and different prices. Although the general outcome of our study will not be affected, this will cause differences in resource use efficiencies.
- Resource use efficiency can be studied for shorter time periods than one year. In the workshop, a number of growers mentioned that this would influence their decision making. It would be worthwhile to explore this further.

- Farms may want to establish a complete Life Cycle Analysis of the new greenhouse. This is a field under development, at least for greenhouse horticulture (Heuts *et al.* 2012; Torrellas *et al.* 2012), and fell beyond the scope of this study.
- Labour in Mexico is cheap. Labour costs are element of our study. If labour costs would rise, then this would stimulate the introduction of labour-saving technologies.

For La Huerta, we foresee the following developments:

- Further intensification as the level of technology increases
- More knowledge-intensive cultivation
- Geothermal heating
- Life Cycle Analyses of the production system
- Participation in a Metropolitan Food Cluster

We recommend that suppliers, either Mexican, from The Netherlands or another country, take notice of the positive and negative aspects of technological innovations that were seen by the Mexican growers. The importance of these points lies in the fact that they must be built upon (the positive points) or dealt with (the negative points). Positive points offer important building blocks for transition. If a negative point made is valid, then a solution must be found, if it concerns only a perceived problem then an awareness activity must be organized, and if an easy solution to a problem exists, then naturally this solution must be offered.

5 References

Bot, G.P.A., 1983.
Greenhouse climate: from physical processes to a dynamic model. Agricultural University of Wageningen, Wageningen.

De Zwart, H.F., 1996.
Analyzing energy-saving options in greenhouse cultivation using a simulation model. Agricultural University of Wageningen, The Netherlands, p. 236.

García Victoria, N., van der Valk, O., and Elings, A., 2011.
Mexican protected horticulture. Production and market of Mexican protected horticulture described and analyzed. Wageningen UR Greenhouse Horticulture Report GTB-1126.

Heuts, R.F., Loon, J. van, and Schrevens, E., 2012.
Life Cycle Assessment of Different Heating Systems for Glasshouse Tomato Production in Flanders, Belgium. Acta Horticulturae 957: 107-114.

Mansfeld, M. van, S. Buijs, P. Smeets, O. van der Valk, E. Zwartkruis, A. Simons, R. van der Geest, M. Koopmans L. Miguel Ayala, N. de Groot, K. Roest, J. Groot, E. Velázquez, V.M. Parada, N. Perez, A. Bruinsma, *et al.* 2012. Sustainable development of a Metropolitan Food Cluster Agrosfera, Aguascalientes Mexico. Wageningen UR.

Stanghellini, C., 1987.
Transpiration of greenhouse crops : an aid to climate management. Agricultural University of Wageningen, The Netherlands, p. 150.

Stanghellini, C., Kempkes, F.L.K., Knies, P., 2003.
Enhancing environmental quality in agricultural systems, In: Pardossi, A. (Ed.), International Symposium on Managing greenhouse crops in saline environment. ISHS, Italy, pp. 277-283.

Torrellas,M., Antón, A., Ruijs, M., García Victoria, N., Stanghellini, C., Montero, J.I., 2011.
Environmental and economic assessment of protected crops in four European scenarios. Journal of Cleaner Production 28: 45-55.

Vanthoor, B., 2011.
A model-based greenhouse design method, Wageningen UR. Wageningen UR Wageningen, p. 307.

Vermeulen, P.C.M., 2010.
Kwantitatieve Informatie voor de Glastuinbouw 2010.
Wageningen UR Greenhouse Horticulture, Bleiswijk.

Annex I Description dynamic climate model Kaspro and input data

In this study the KASPRO model is used. This extensive dynamic simulation model simulates a full-scale virtual greenhouse based on the greenhouse construction elements, ventilation openings, greenhouse equipment, different covering materials and their properties (transmission, reflection, and emission), set points for inside climate and the outside climate of a given location. Any computed physical quantity can be listed as output, but for the current project the observed output comprises the realised greenhouse climate at every hour of the year, the energy consumption, the amount of water evaporated by the crop, the amount of CO_2 applied and the dry matter production of the crop.

The model is based on the computation of relevant heat and mass balances (Bot, 1983). The heat balances describe both the convective and irradiative processes. The mass balances are constituted from exchange processes through leakage and ventilation (de Jong, 1990). They include canopy transpiration (Stanghellini, 1987) and condensation at cold surfaces. The mass balances around the CO_2-concentration are based on losses of CO_2 by ventilation and photosynthesis, and gains of CO_2 by dosing and respiration.

Basically, the model describes the entrance of solar radiation into a greenhouse structure and computes the heat and moisture fluxes induced from this radiation. The heat and moisture is released predominantly by the canopy, but the heat fluxes originate from other opaque elements in the envelope as well. Also, reflection of solar radiation, typically by the covering structure and by reflecting shading screens, is taken into account. The heat and moisture fluxes affect the air conditions around the canopy, which are in dynamic interaction with the greenhouse construction and the environment. To a certain extent, the interaction between the microclimate around the canopy and the environment can be controlled by means of heating, ventilation, humidification and dehumidification, CO_2 application, shading and optionally even by means of cooling.

Greenhouse climate is controlled by a replica of commercially available climate controllers. The total set of differential equations is solved numerically (de Zwart, 1996). The control actions coming from the greenhouse climate controller are an integral part of the simulation model. According to user defined settings for the inside climate conditions that are to be achieved the controller increases or decreases the heating power, opens or closes the ventilation openings, applies fogging and CO_2 enrichment, opens or closes screening tissues and turns on cooling system.

For this project, the KASPRO simulation model was used to analyse the effect of local outside climate conditions on inside greenhouse climate and crop response with an assumed greenhouse configuration. The effect of cooling by natural ventilation or evaporative cooling by fogging and mechanical cooling was analysed.

The result of all KASPRO simulations were the realised greenhouse climate at every hour of the year, the energy consumption, the amount of water transpired by the crop, the amount of CO_2 applied and the dry matter production of the crop for different scenario's. These results were then used to feed the economic model.

Annex II Assumptions for the economic analysis

Table 8. Variable costs.

Item	Price (MX $)	source of information
natural gas [price/m3]	$ 11.49	*La Huerta*
electricity [price/kWh]	$ 0.37	*La Huerta*
CO_2 [price/kg] pure	$ 3.27	*not known*
plant material [price/plant]	$ 15.69	*La Huerta*
labour costs crop [price/h]	$ 36.27	*La Huerta*
crop protection [price/m2]	$ 16.34	*La Huerta*
crop nutrition closed cycle [price/m2]	$ 14.71	*KWIN**
water [price/m3] (water system, transpiration, fogging)	$ 0.64	*La Huerta*
substrate	$ 21.24	*KWIN**
plastic film, wires, clips	$ 8.17	*KWIN**
packaging /sorting etc.	$ -	*to be determined*
rent for land	$ -	Not included

*KWIN: *(Vermeulen, 2010)*

Table 9. Product prices. The domestic and export prices have been provided by Huerta for 2010 and 2011 together with their production ratio over the production period for domestic and export. Based on this information tomato prices for every month have been calculated.

Price 1 kg of tomato in mex. $	Domestic and export price combined	Export price
January	22.10	25.35
February	17.38	22.49
March	13.65	15.08
April	10.40	11.05
May (assumed)	10.40	6.50
June (assumed)	10.40	6.50
July (assumed)	10.40	6.50
August (assumed)	10.40	6.50
September	11.83	21.32
October	12.22	13.78
November	13.91	15.99
December	17.42	19.76

Table 10. Investment costs per m^2 greenhouse ground area

Item	**Overall investment price/m2**	**depreciation [%/year]**	**maintenance [%/year]**	**interest rate [%/ year]**	**Yearly costs price/ m²**	source of information
modern glass greenhouse incl. covering (1 ha)	$ 547.39	7	0.5	4	$ 62.95	*KWIN*
glass covering (diffuse, extra)	$ 261.44	7	0.5	4	$ 30.07	*Dutch industry*
double glazing	$ 196.08	7	0.5	4	$ 22.55	*Dutch industry*
modern plastic film greenhouse (excl. covering)	$ 294.12	15	2	4	$ 61.77	*KWIN*
plastic film covering	$ 24.51	30	5	4	$ 9.56	*KWIN*
Traditional plastic film greenhouse	$ 130.72	15	2	4	$ 27.45	*KWIN*
Net greenhouses	$ 138.89	15	2	4	$ 29.17	*KWIN*
Net	$ 32.68	30	5	4	$ 12.75	*KWIN*
Concrete paths (5% greenhouse area)	$ 20.43	7	1	4	$ 2.45	*KWIN*
Concrete floor	$ 637.26	7	1	4	$ 76.47	*KWIN*
Heating system in the greenhouse	$ 103.76	7	0.5	4	$ 11.93	*KWIN*
Growing pipe in the greenhouse	$ 39.22	7	0.5	4	$ 4.51	*KWIN*
heating system (boiler) 100 W/m^2, 1 ha	$ 98.04	7	1	4	$ 11.76	*KWIN*
air heating unit (13 m^3/ hour), 1 per 100 m^2	$ 334.97	15	2.5	4	$ 72.02	*KWIN*
heat storage, 120 m^3	$ 104.58	7	2	4	$ 13.59	*KWIN*
Piping	$ 32.68	7	0.5	4	$ 3.76	*KWIN*
Cooling system (heat pump) 500 W/m^2, 1 ha	$ 1,143.80	7	2	4	$ 148.69	*KWIN*
Cooler in the greenhouse every 50 m^2	$ 653.60	7	2	4	$ 84.97	*KWIN*
screening system	$ 130.72	25	5	4	$ 44.44	*KWIN*
insect netting	$ 122.55	20	2	4	$ 31.86	*KWIN*
CO_2 dosing (1ha) + detection	$ 14.22	10	5	4	$ 2.70	*KWIN*
fogging system	$ 81.70	10	5	4	$ 15.52	*KWIN*
dehumidification system (outside air)	$ 302.29	10	5	4	$ 57.44	*KWIN*
Pad and Fan system (35 m)	$ 408.50	15	5	4	$ 98.04	*assumption*
Fertigation system A B container and drippers	$ 46.57	15	5	4	$ 11.18	*KWIN*
Water storage tanks	$ 16.34	15	5	4	$ 3.92	*KWIN*
re-circulation and desinfection	$ 57.19	7	2	4	$ 7.43	*KWIN*
RO installation (50 m^3/day)	$ 46.57	7	2	4	$ 6.05	*KWIN*
artificial lighting (60W/m)	$ 571.90	15	1	4	$ 114.38	*KWIN*
climate computer simple	$ 16.34	15	8	4	$ 4.41	*KWIN*
climate computer advanced	$ 57.19	15	8	4	$ 15.44	*KWIN*
Building (computer, kantine, storage, packaging etc) 10% of greenhouse	$ 849.68	7	0.5	4	$ 97.71	*KWIN*
Storage (cooled) 1% greenhouse area	$ 1,470.60	7	1	4	$ 176.47	*KWIN*
Gutters (m^{-2})	$ 114.38	12.5	1	4	$ 20.02	*KWIN*

Annex III Assumptions for simulation model

- The plastic greenhouse has a 20% lower light transmissivity than the glass greenhouse and has a diffusing capacity of 40%.
- The effect of soilless culture compared to soil bound cultivation cannot be simulated. From literature data we can assume that production in soil bound cultivation is 60% of what can be produced in soilless culture.
- Humidity control is applied when the humidity is above 85% in the greenhouse.
- The maximum leaf area index of the crop is 3.
- The characterics of a normal thermal screen are used (SLS 10 Ultra 10). The screen is closed when the light level drops below 50W/m^2 and the outside temperature is less than 12 degrees Celsius.
- The electricity use is converted into energy use by assuming the electricity is produced with an efficiency of 42%.

Annex IV Scenario results

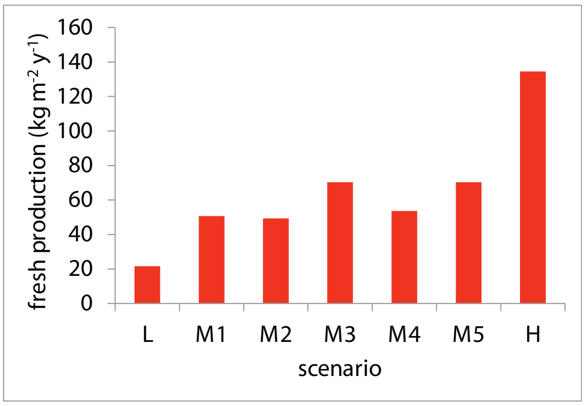
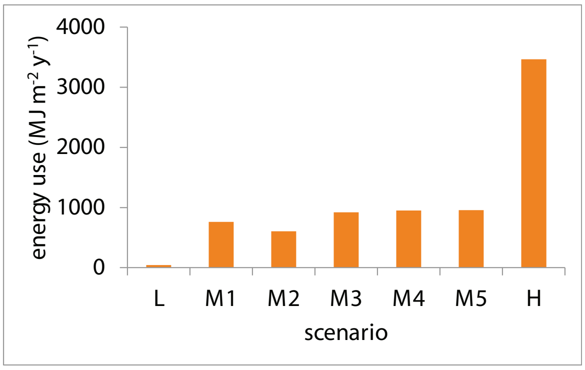


Figure 16. Annual fresh tomato production for the various scenarios (values are computed).



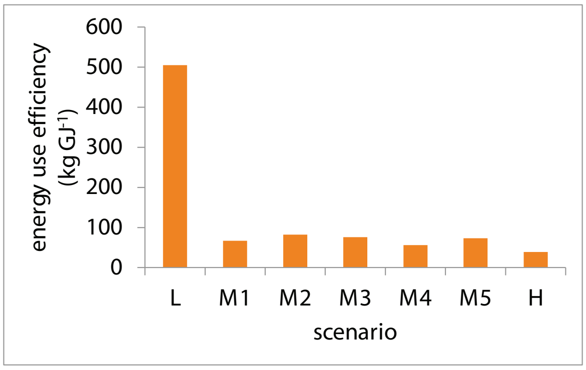
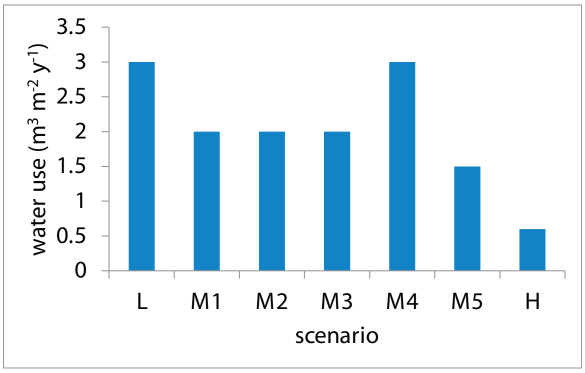


Figure 17. Annual energy use and energy use efficiency for the various scenarios (values are computed).



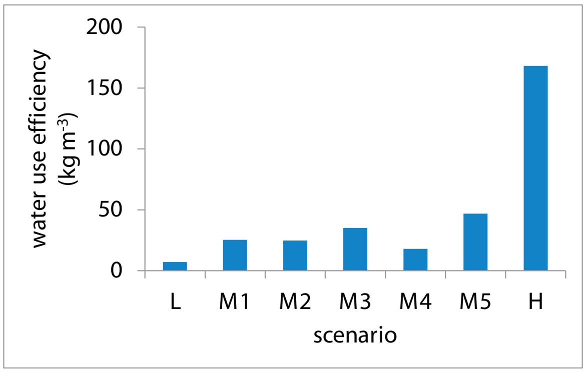


Figure 18. Annual water use and water use efficiency for the various scenarios (values are computed).

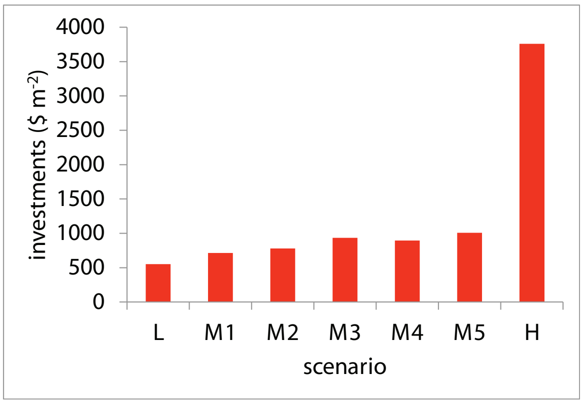


Figure 19. Total investments for greenhouse construction and installation for the various scenarios (values are computed).

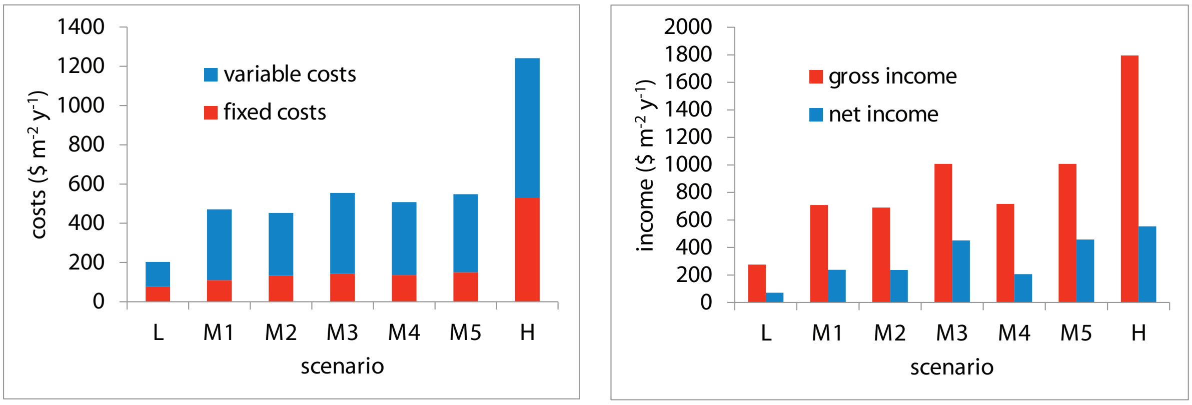


Figure 20. Annual variable and fixed costs, and gross and net income for the various scenarios (values are computed).

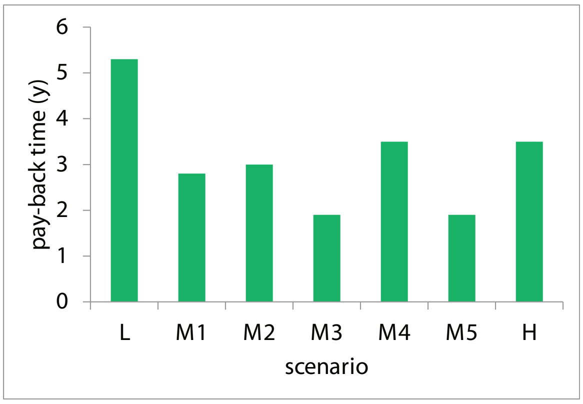


Figure 21. Pay-back time for the various scenarios (values are computed).

Wageningen UR Greenhouse Horticulture

Adres : Droevendaalsesteeg 1, 6708 PB Wageningen
: Postbus 644, 6700 AP Wageningen
Tel. : 0317 - 48 60 01
Fax : 0317 - 41 80 94
E-mail : glastuinbouw@wur.nl
Internet : www.glastuinbouw.wur.nl

Projectnumber Wageningen UR Greenhouse Horticulture: 3242074800

Landbouw Economisch Instituut

Adress : P.O. Box 29703, 2502 LS The Hague, The Netherlands
Tel. : +31 - 70 - 3358330
Fax : +31 - 70 - 3615624
E-mail : informatie.lei@wur.nl
Internet : www.lei.wur.nl

Ministerie van Economische Zaken

Projectnummer: 3242113112