EIP-AGRI Focus Group

Circular Horticulture

STARTING PAPER

funded by European Commission

Starting Paper: FG27 Circular horticulture

Contents

1. Introduction 3
2. The greenhouse potential 4
3. Existing practices/examples of circular protected horticultural systems8
   3.1. Water and nutrients recycling 8
   3.2. Substrates.. 9
   3.3. Plastics and paper 10
   3.4. Crop residues 10
4. Clustering in protected horticulture to increase circularity 10
5. Success factors and barriers for circularity 11
6. Discussion questions 12
7. Reference List 13
8. Annex 1. Statistics on protected cultivation in the EU 16

Facilitation Team

Alexandre MORIN, Task Manager, EIP-Agri Service Point

Nikolaos KATSOULAS, Coordinating Expert, University of Thessaly, Greece / EIP-Agri Service Point

Koen DESIMPELAERE, EIP-Agri Service Point

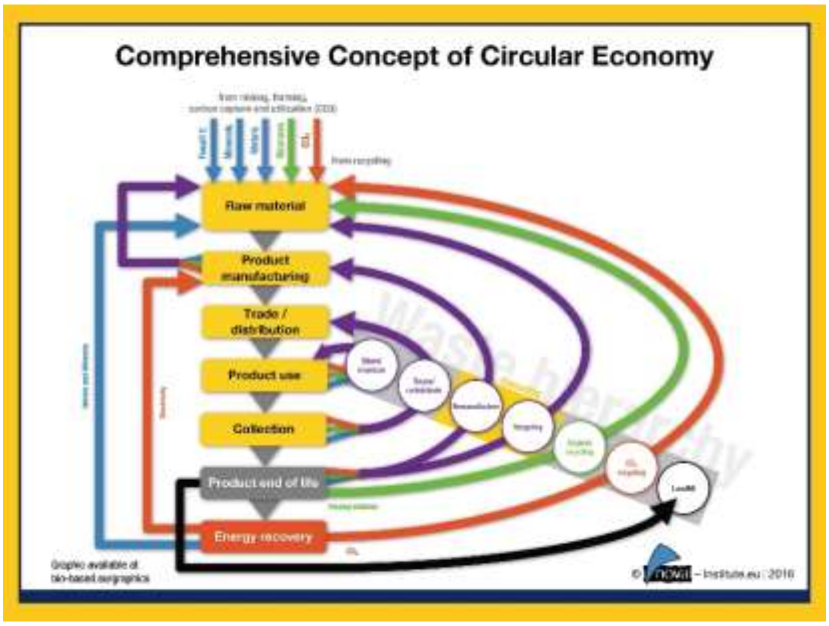
Sirpa KARKALAINEN, EC–DG-Agri

Annette SCHNEEGANS, EC–DG-Agri

funded by European Commission

1. Introduction

The challenges to feed the world in 2050 are becoming more and clearer. This calls for producing more with less inputs (most of them under scarcity), higher resource efficiency, minimum or zero effect on the environment and with higher sustainability. Therefore, the need to increase circularity of production systems is highly significant for their sustainability. Circular Economy is defined an economic system that replaces the 'end-of-life' concept with restoration, shifts towards the use of renewable energy, eliminates the use of toxic chemicals, which impair reuse, and aims for the elimination of waste through the superior design of materials, products, systems, and, within this, business models. A circular economy system is comprised by the 4R components that is reducing, alternatively reusing, recycling and recovering materials in production/distribution and consumption processes. Waste streams and emissions would be used to create value, providing secure and affordable supplies of raw materials and reducing the pressure on the environment. It operates at the micro level (products, companies, consumers), meso level (eco-industrial parks) and macro level (city, region, nation and beyond), with the aim to accomplish sustainable development, thus simultaneously creating environmental quality, economic prosperity and social equity, to the benefit of current and future generations. Circular economy systems require fundamental changes simultaneously at the micro, meso and macro system, something that indicates that circular economy requires a systemic change (Kirchherr et al., 2017) and a more holistic, integrated approach which takes into account the myriad of inter-linkages within and between sectors, within and across value chains and between actors. Such an approach would help to take into account the different incentives in play, the distribution of economic rewards and impacts of specific measures along a value chain, across different sectors and policy areas. It needs novel business models and responsible consumers, thus, the promotion of consumer responsibility is crucial for circular economy (Ghisellini et al., 2016). Probably organic farming, where closed cycles using internal resources and inputs are preferred to open cycles based on external resources, is a farming systems with principles (e.g. respect nature's systems and cycles) very close to those of circular economy.



<u>What does the concept of circular horticulture mean in the context of protected horticulture – how is it translated into practices?</u>

Protected horticulture offers opportunities for maximum resource efficiency across various levels and within and between farms and at regional level), high quality production and contributes greatly to the nutrition security as part of the world food production. This is achieved by both simple and advanced techniques for farm, crop and climate management, precise application of resources (water, fertilisers, energy), so that environmental impact can be controlled and the use of resources optimized. Greenhouses are relevant for circularity due to (i) their potential for high productivity with reduced water and agrochemicals use per unit of production, (ii) their production capacity up to 10 times higher than open field-based agriculture per ha and (iii) their high potential for the recycling of water and nutrients.

The purpose of this starting paper is to serve as an input to the first meeting of the European Innovation Partnership (EIP) Focus group on Circular Horticulture (FG-27) with special emphasis in circularity in protected horticulture. Aim of FG-27 is to look at examples of good practice of circularity in protected horticulture and how these can be transferred to other situations to benefit the wider sector. It will also look at success and fail factors for circular approaches in horticulture, identify knowledge gaps and possible future research needs. The Focus Group is expected to carry out the following main tasks:

- Assess existing practices in protected horticulture and their potential to better re-use or recycle water, materials and by-products, identify good practices and success stories from different parts of Europe, taking into account different climatic conditions, agro systems and specifically focusing on farmers' and advisers' experiences.
- Compare different management practices taking into account the feasibility and cost- effectiveness at individual farm level or through collective approaches, and identify success factors (such as *knowledge requirements, crucial partnerships*) and technical/economic barriers, or other fail factors.
- Identify how these practices may be transferred to other conditions (e.g. location, type of production) and how.
- Identify tools to help farmers and advisers in assessing the opportunities for re-use and re-cycling of resource inputs at farm and regional levels.
- Identify innovative business models for horticultural enterprises.
- Identify further research needs from practice, possible gaps in technical knowledge, and further research needs.
- Suggest innovative solutions and provide ideas for EIP-AGRI Operational Groups and other innovative projects.

The FG-27 will meet on 29 and 30 of November 2017 for first time to discuss how it can complete the above tasks. In order to advance the circularity in protected cultivation, the Focus group will be divided in subgroups and develop mini papers in major subjects that affect circularity.

2. The greenhouse potential

The area under protected cultivation is steadily increasing in the EU (estimated total area during 2015 of about 175000 ha[1], increase rate of about 4.5% from 2005 to 2013) and the Mediterranean region (total area of about 120000 ha, 2016), since protected cultivation constitutes the most productive form of primary agricultural production (see Annex 1. Statistics on protected cultivation in the EU). The Netherlands and Spain are greenhouse hotspots but other countries including Italy, France and Greece are expanding their industries. China has an enormous greenhouse industry, which is a response to its serious soil depletion problem.

Some of the reasons that lead to the increase of protected cultivation are: (i) ability of greenhouses to obtain high resource use efficiency and provide high-quality products all-year round (ii) extreme and unpredictable outside climate conditions as a result of climate change and ability of greenhouses to disconnect to some degree internal and external climate conditions, (iii) water shortage, which is critical especially in Mediterranean countries, (iv) environmental pollution & food security problems; and other. In some cases, year round production or cultivation of certain crops is possible only in greenhouses.

[1] About 5250 ha are organic farming greenhouses (~2000 ha Spain; ~2,000 ha Italy, ~600 ha France, ~260 ha Germany, and the rest are in The Netherlands, UK, Switzerland, Belgium, Austria, Nordic) which is almost entirely used for fruit vegetables and lettuce.

funded by European Commission

Greenhouse structures and equipment differ around EU depending on the climate conditions and the technologies available in the region, the crop cultivated and other parameters related to the crop market and finance of the greenhouse units. The majority of greenhouses in the Mediterranean are low cost, low tech, rudimentary equipped while in Central and North Europe greenhouse units are of higher investment cost and in the majority of high technological level. The majority of greenhouse crops are grown in the soil but in the last decades, a switching over to soilless production systems is observed due to the benefits offered by hydroponic systems such as control of soilborne pathogens, superiority of physical & hydraulic characteristics of substrates, better control of nutrient availability, pollution prevention and higher water- and nutrients use efficiency and other.

Although hi-tech greenhouses are capable of providing the optimal conditions for year-round production; they constitute the most expensive option, in terms of capital, running costs and energy consumption. Vanthoor et al. (2011) reported that the most profitable infrastructure for a specific region is not necessarily the most expensive one and growers' experience shows that in many cases high profits can also be achieved using intermediate-level greenhouses or low cost structures (Table 1). Similar findings are reported in more studies (e.g. see Table 3, from Torrellas et al., 2012, Vermeulen, 2008).

Table 1. Simulated net financial result of greenhouses in Spain and in the Netherlands (Vanthoor et al., 2011).

Location	Spain (€ m^{-2} $year^{-1}$)	Netherland (€ m^{-2} $year^{-1}$)
Crop yield	22.50	41.73
Fixed costs	6.43	14.57
Variable costs		
Labour	3.63	17.73
Energy	6.54	9.48
Water	0.21	0.00
Electricity	0.00	0.21
CO_2	0.00	0.34
Plant related costs	5.80	8.81
Net financial result	-0.11	-9.41

A low-tech greenhouse diminishes the risk of variations among price paths in different years, whereas a high-tech greenhouse has lower risk from the effect of external climate conditions. Growers with low-tech, simple greenhouses (e.g. Spanish) have less to lose when tomato prices go down, unlike their Dutch counterparts with expensive modern greenhouses. On the other hand, the incomes of Spanish growers are influenced more by climate variations. Best practice examples and tested techniques in one location (e.g. Dutch greenhouses) are not necessarily profitable in other locations.

Protected cultivation and especially high-tech greenhouses and soilless cropping systems have high investment (Table 3) and operational costs (Table 1) and are very resource-intensive compared to open field soil cultivation. Some indicative average values for resources (external inputs) use for a year round soilless tomato crop may be as follows: water: 1.8 m^3 m^{-2} y^{-1}; fertilisers: 3.2 kg m^{-2} y^{-1}; energy for heating: 750 MJ m^{-2} y^{-1}; substrate: 20 L m^{-2} y^{-1}; plastics for greenhouse and soil covering: 0.18 kg m^{-2} y^{-1}; paper for packaging: 2.8 kg m^{-2} y^{-1}.

funded by European Commission

As far as water and nutrients is concerned, protected horticulture may be considered partially circular since plants can grow in closed systems where water and nutrients are recirculated and reused. High-tech and sophisticated greenhouse systems (mainly in Central and North Europe) can obtain a relatively high degree of circularity for inputs such as water and fertilisers. Closed and recirculating hydroponic systems require high investment and running costs which are currently possible in the Mediterranean greenhouses only for high-value crops. Although zero emissions are within reach for water and nutrients in these greenhouses, this is not the case in low-tech greenhouses (found mainly in South Europe and Mediterranean regions). Those industries are largely non-circular at the moment because they have not optimised their nutrient flows and there is long way from high rate of recycling.

The degree of circularity for the technical material for production and post-production (e.g. substrate, plastic, crop biomass) is very low in both high and low tech greenhouses. The disposal of used artificial growing media represents one of the weak points for the application of hydroponic technology to greenhouse and nursery production. In most of the cases, exhausted substrates, used plastic covers and crop biomass wastes are disposed to landfill. Several technologies do exist that could help to exploit the above residues and turn them into products used as raw material in the same or another production cycle. Callejón-Ferre et al. (2011) studied the energy potential of the greenhouse crop remains in Almeria. They found that the dry biomass that could be potentially collected from a total area of about 39000 ha was about 250000 t year^{-1} and its potential energy was 1003500 MWh year^{-1} (or about 3613000 GJ year^{-1}). The developed methods allow reusing greenhouse crop residues as fuel in greenhouses, to provide heat and CO_2, thus its utilization can suppose an economic yield and, also, enhance sustainability for this commercial activity (Reinoso Moreno et al., 2017). Still some difficulties need to be solved to do this technology suitable. Major bottlenecks are related with the high moisture and ash content, in addition to low energetic density of these residues.

Table 2. Crop residue biomass produced and energy potential by the greenhouse agriculture industry in Almería (combination of tables 1 and 6 from Callejón-Ferre et al., 2011).

Studied species	Plant remains (t ha^{-1} year^{-1})	Area occupied (ha)	Biomass (t year^{-1}) fresh weight	Biomass (t year^{-1}) dry weight	Energy potential (MJ year^{-1})
Cucurbita pepo L.	20	4492	89840	17968	230877.48
Cucumis sativus L.	24	4551	109224	21844.8	275153.17
Solanum melongena L.	27	1622	43794	8758.8	144780.42
Solanum lycopersicum L.	49	10250	502250	100450	1489350.05
Phaseoulus vulgaris L.	23	1259	28957	5791.4	98536.21
Capsicum annuum L.	28	7057	197596	39519.2	603238.46
Citrillus vulgaris Schrad.	24	4775	114600	22920	326806.65
Cucumis melo L.	33	4981	164373	32874.6	443848.52
Total	228	38987	1086261	250126.8	3612590968.31

The greenhouse of the future must have nearly zero environmental impact. This goal can be achieved by developing a sustainable greenhouse system that: does not need any fossil energy and minimizes carbon footprint of equipment; with no waste of water nor emission of fertilizers and full recycling of the substrate; with minimal need of plant protective chemicals, yet with high productivity and resource use efficiency.

Torrellas et al. (2012) analysed the environmental and economic profile of current agricultural practices for greenhouse crops, in cold and warm climates in Europe, using four scenarios as reference systems (Table 3): tomato crop in a plastic greenhouse in Spain, and in glasshouses in Hungary and the Netherlands, and rose crop in a glasshouse in the Netherlands.

Table 3. Main characteristics of the four scenarios studied in Torrellas et al. (2012).

	Scenario 1	Scenario 2	Scenario 3	Scenario 4
	Tomato, multi-tunnel, Spain	Tomato, Venlo, Hungary	Tomato, Venlo, the Netherlands	Rose, Venlo, the Netherlands
FU	1 ton tomato	1 ton tomato	1 ton tomato	1000 stems
Yield	16.5 kg·m^{-2}·y^{-1}	48 kg·m^{-2}·y^{-1}	56.5 kg·m^{-2}·y^{-1}	276 stems·m^{-2}·y^{-1}
Crop period	52 weeks	49 weeks	52 weeks	4 years
Substrate	Perlite	Rockwool	Rockwool	Rockwool
Fertirrigation system	Drippers Open-loop	Drippers Open-loop	Drippers Closed-loop Disinfection (heating)	Drippers Closed-loop Disinfection (heating)
Water source	Well	Well	Rainwater tank	Rainwater tank
Water (l·m^{-2})	475	700	794	902
Water use	28.8 l·kg^{-1}	14.6 l·kg^{-1}	14.1 l·kg^{-1}	3.3 l·stem^{-1}
Climate system	Natural ventilation	Heating	Co-generation	Co-generation
Energy source	no	Geothermal water	Natural gas	Natural gas
Lighting	no	no	no	yes
Energy screen	no	yes	yes	yes
CO_2 enrichment	no	yes	yes	yes
Waste disposal emissions	Transport Landfill	Transport Landfill	Transport Landfill Incineration	Transport Landfill Incineration
Average product price	0.58 €·kg^{-1}	0.79 €·kg^{-1}	0.82 €·kg^{-1}	0.38 €·stem^{-1}
Cultivation labour (hours/1000 m^2)	255	1700	950	1600
Total costs	9.01	30.72	58.30	113.46
Gross income (€ m^{-2})	9.57	37.92	46.33	104.88
Net income (€ m^{-2})	0.56	7.20	-11.97	-8.58
Investment (€ m^{-2})	26	85	116	186

A comparison of the environmental effects of low tech greenhouses in Spain (scenario 1) and high tech greenhouses in the Netherlands (scenario 3) showed that high tech greenhouses have higher total impact to the environment than the Spanish greenhouses (Table 4, combination of tables 3.14 and 5.15 from Montero et al., 2011).

Table 4. Comparison of Life Cycle Impact Assessment* of tomato producing greenhouses in Spain and in the Netherlands.

LCIA results per FU, for tomato greenhouse crop Spain.

No	Unit	Total	Structure	Climate system	Auxiliary equipment	Fertilizers	Pesticides	Waste
AD	kg Sb eq	**1,7E+00**	**7,8E-01**	1,1E-03	6,3E-01	2,0E-01	1,7E-02	2,3E-02
AA	kg SO2 eq	**1,0E+00**	3,0E-01	1,5E-03	**4,2E-01**	2,1E-01	1,9E-02	1,2E-02
EU	kg PO4---eq	**4,8E-01**	1,5E-01	2,7E-04	8,0E-02	**2,8E-01**	6,5E-03	3,8E-03
GW	kg CO2 eq	**2,5E+02**	**8,8E+01**	1,5E-01	7,7E+01	8,2E+01	3,0E+00	3,1E+00
PO	kg C2H4	**6,4E-02**	2,0E-02	5,4E-05	**2,7E-02**	4,9E-03	1,2E-03	1,0E-03
CE	MJ	**4,0E+03**	**1,9E+03**	3,1E+00	1,8E+03	3,9E+02	4,1E+01	5,7E+01

LCIA results per FU, for tomato greenhouse crop in the Netherlands, with cogeneration (production of electricity is considered "avoided electricity")

No	Unit	Total	Structure	Climate system	Auxiliary equipment	Fertilizers	Pesticides	Waste
AD	kg Sb eq	**5.6E+00**	3.4E-01	**5.0E+00**	1.4E-01	9.9E-02	1.8E-03	3.3E-03
AA	kg SO_2 eq	**1.2E+00**	3.0E-01	**6.6E-01**	8.8E-02	1.1E-01	1.8E-03	2.3E-03
EU	kg PO_4^{-} eq	**-1.1E+00**	**9.7E-02**	-1.3E+00	2.1E-02	1.6E-02	6.1E-04	9.1E-04
GW	kg CO_2 eq	**7.8E+02**	5.3E+01	**6.6E+02**	1.4E+01	4.8E+01	2.0E-01	2.1E+00
PO	kg C_2H_4	**1.9E-01**	1.4E-02	**1.6E-01**	6.5E-03	2.2E-03	1.1E-04	7.6E-05
CED	MJ	**1.2E+04**	5.2E+02	**1.1E+04**	3.1E+02	2.0E+02	3.9E+00	7.9E+00

*impact categories: AD: Abiotic depletion potential; AA: Air acidification potential; EU: Eutrophication potential; GW: Global warming potential 100 years; PO: Photochemical oxidation potential; CE: Cumulative energy demand. The functional unit was one tonne of tomatoes.

The higher environmental impact of the greenhouses in the Netherlands is associated to the greenhouse climate control, structure, and auxiliary equipment. Montero et al. (2011) noted that the environmental impacts due to fossil based energy consumption can be reduced by using co-generation, bio-energy or renewable energy (e.g. geothermal water) in greenhouses. The structure contribution can be decreased with the improvement of recycled materials and design. When the comparison between the high and low-tech greenhouses was made only for the impact related to the fertilisers and pesticides used and the waste produced, the impact of high-tech greenhouses was lower than that of the low-tech (Montero et al., 2011). Thus, adjustment of fertilizer doses and closed irrigation systems are recommended for low-tech greenhouses. To reduce the pollution from leachates in a greenhouse soilless tomato crop, Muñoz et al. (2017) demonstrated the potential to grow a greenhouse soilless tomato crop with a leaching fraction of 40% and directly reuse leachates to fertigate an open-field crop rotation sequence of lettuce, tomato and endive with satisfactory commercial yields. The best economic perspectives to reduce inputs are energy savings in for high tech greenhouses in Central and North Europe and reduction of fertilizers in low-tech Mediterranean greenhouses.

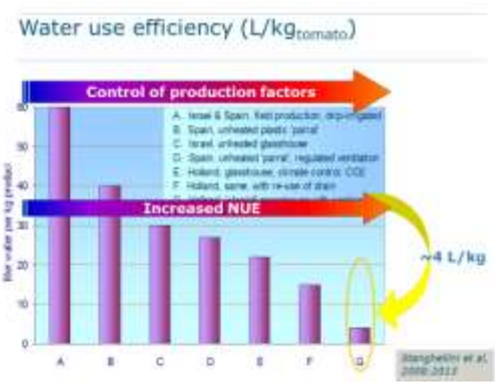
funded by European Commission

Several projects and thematic networks deal with the resource use efficiency and increase of circularity in protected cultivation (Closys[2], Sirrimed[3], Euphoros[4], OrganicGH[5], EU Aquaponics Hub[6], Adapt2Change[7], OpIRIS[8], Flow-Aid[9], Fertinnowa[10], Euvrin[11] and other). Though extensive research has been carried out in greenhouse related programs and there are quite a lot of mature research results, there is a gap in the integration of these results in the production process.

3. Existing practices/examples of circular protected horticultural systems

3.1. Water and nutrients recycling

Under semi-arid growing conditions, like those found in Mediterranean regions, greenhouse crops (grown in open hydroponic systems or in the soil) are over-irrigated (so that growers prevent water and nutrient shortages). The excess (about 40%) nutrient solution contains not only fertilisers but also residues from the agrochemicals used in the greenhouse. This excess, when discharged to the surroundings or filtrated to deeper soil levels, results in environmental pollution and increase of NO_3^-N concentration in underground water. Lessons may have to be taken from organic greenhouse production where the use of irrigation to flush surplus nutrients is not an acceptable practice consistent with the organic principles. When choosing the quantity and type of fertilisers in organic farming, the nutrient balances must be taken into consideration to avoid salinization or leaching of nutrients.



Soilless crops: When good quality water is available and closed soilless/hydroponic systems are used, protected horticultural systems can reach a relatively high degree of circularity for water and nutrients. The product water use (PWU, in L of water needed per kg of production, usually estimated per cultivation period or per year) values reported for the Netherlands in high-tech greenhouses (Stanghellini et al. 2003) for tomato grown in closed- and open-loop irrigation systems, respectively, are 15 and 22 L water per kg tomato. However, for greenhouses in Southern Italy the reported PWU values (Santamaria et al., 2003; Valenzano et al., 2008) range from 45.5 L kg^{-1} to 22 L kg^{-1}, depending on the cultivation period, the hydroponic system, the irrigation system and the tomato type.

Sensors, Models and Decision Support Systems (DSS): Soil moisture and substrate water content sensors can make an important contribution to crop water and nutrient management by ensuring that crops have adequate water status and by limiting drainage thereby ensuring minimal nutrient leaching loss. Thompson and Voogt (2014) presented the advances of irrigation management using soil moisture sensors and irrigating in accordance with the crop demand and cropping conditions. Several models and decision support systems (DSS) have been developed that could be effective for optimising water and fertiliser management (see also the relative mini-paper of the EIP FG 'Fertiliser efficiency - Focus on horticulture in open field' on Nitrogen and

---

[2] http://cordis.europa.eu/project/rcn/54722_en.html
[3] http://www.sirrimed.org
[4] http://www.wur.nl/en/Research-Results/Projects-and-programmes/Euphoros-1.htm
[5] http://www.cost.eu/COST_Actions/fa/FA1105
[6] http://www.cost.eu/COST_Actions/fa/FA1305
[7] https://www.adapt2change.eu
[8] http://www.opiris.eu
[9] http://cordis.europa.eu/result/rcn/47753_en.html
[10] http://www.fertinnowa.com
[11] http://euvrin.eu

funded by European Commission

water need based on a model by Carranca and Martínez-Gaitán., 2014) and application in vegetable production, and whose extensive use would increase the circularity and reduce the environmental impact associated with current irrigation and fertilisation management practices in protected horticulture. DSSs provide customised recommendations for water and fertilisation or irrigation management that are specific for individual crops, sites and conditions [e.g. Waterstreams (Voogt et al., 2012); Veg-Syst-DSS (Gallardo et al., 2016); OpIRIS (Katsoulas et al., 2017)]. The DSSs use different approaches for simulating the processes. Some have been calibrated/validated for specific crops, cultivation systems and environmental (climate and soil) conditions.

Semi-closed greenhouse: Another technology that results in high water use efficiency (WUE, kg of production per L of water used, usually estimated per cultivation period or per year) is the closed or semi-closed greenhouse concept that aims at covering heating, cooling and dehumidification needs of the greenhouse with minimal use of resources (De Gelder et al., 2012). Semi-closed greenhouses are fit with some cooling and/or dehumidification systems which are also used to recover transpired water from the greenhouse air, thereby reducing greenhouse water needs and increasing greenhouse water use efficiency.

Aquaponics: the symbiotic growing of fish and vegetables in recirculating water systems – is emerging as one of the most important areas of sustainable agriculture. The classical working principle of aquaponics is to provide nutrient-rich aquacultural water to a hydroponic plant culture unit, which in turn depurates the water that is returned to the aquaculture tanks. The combined hydroponic and aquaculture system reduces overall water discharge and increases overall WUE. A known drawback is that a compromise away from optimal growing conditions for plants and fish must be achieved to produce both crops and fish in the same nutrient solution (EU Aquaponics Hub). Körner et al. (2017) showed that the greenhouse climate is influenced through the aquaculture system with increased humidity levels and decreased use of energy for heating and CO_2 supply. The amount of energy saving for greenhouse heating increases with fish pond water temperature, while due to the metabolic activity inside the aquaculture system energy consumption for heating the water increased only little in that range. Based on circularity and synergy concept, Sybimar Ltd[12] developed a bioenergy and food production solution based on closed circulation, where waste, waste heat, nutrients and CO_2 are used and recycled back to energy and food production. Other working examples (small or higher scale, high or low-tech production systems) may exist and will have to be discussed in the FG.

3.2. Substrates

Substrates (artificial growing media) used in protected cultivation are regularly reused (used for the cultivation of the same or similar crops), recycled (are reprocessed into materials either for the original or other applications) or discarded to the environment, the last being a potential threat to the environment due to a number of reasons (may contain pesticides, affect the landscape visual amenity when discarded illegally).

More than 10 and 20-25 L m^{-2} are necessary for greenhouse cultivation, respectively, in rockwool and in perlite. The total estimated volume of growing media used yearly in the EU is around 40 million m^3.

The chance of reusing exhausted substrates depends on the physical-chemical properties of the material as well as on the crop's attitude (related to its tolerance to abiotic and/or biotic stresses due to such a reuse). The number of growing cycles a substrate can be reused depends on its nature and the type of crop. Generally, inorganic substrates tend to last longer, perlite up to 2-3 years; rockwool up to 3 years. Organic substrates have a shorter life, up to 2-3 years, due to minor bio-stability.

Montero et al. (2011) used Life Cycle Assessment (LCA) tool to evaluate several greenhouse production systems in Europe and concluded that substrate manufacturing has an important environmental burden. Thus, the reutilization of substrate must be strongly encouraged along with the reduction of substrate volume.

When direct reuse as growing media is not feasible and the option of disposal (not considered as reuse or recycling) in landfill is not available, exhausted substrates can be used as soil amendment (e.g. to improve poor physical properties of clay soil) or mixed with other substrates. In some cases, the need to find solutions for used media lead to the development of yet another new media by their recycling. An example is the incorporation of recycled stone wool as a component in peat-based media (chopped small particles into peat

[12] http://www.sybimar.fi/en

to increase porosity and water holding capacity of the mixture and reduce the use of non-renewable material as peat). In The Netherlands, nearly all (90%) used rockwool slabs is currently collected and processed at large-scale facilities (located in the Netherlands and in Belgium), where they are turned into bricks for houses or re-manufactured into horticultural or insulation rockwool. Exhausted perlite may be also used into construction blocks.

3.3. Plastics and paper

Most greenhouses use large amounts of plastic including pots, flats, hanging baskets, greenhouse film, drip irrigation tape, plastic plant labels and plastic containers for agrochemicals. The circularity in plastics use in protected horticulture is very low and thus, the extensive use of plastic has resulted in a significant waste disposal problem. Opportunities for recycling have increased in recent years due to high oil prices that have resulted in increased prices for recycled plastics, as well as growing consumer interest in recycling. The plastic material used for greenhouse covering and greenhouse soil mulching may be recycled and used from plastics recycling units to produce materials that could be used again in the greenhouse (like covering films or soil mulching films) or for other uses (e.g. plastic bags, irrigation pipes etc).

Greenhouse units that sell packaged products usually use paper containers. The containers are sold with the product and the only way to circulate the paper material is through recycling by the consumers. The same could also hold for plastic pots used mainly in potted ornamental plants.

3.4. Crop residues

Depending on the cultivated crop, greenhouses may produce large amounts of crop residues that could be recirculated. Crop residues could be used directly as biomass for greenhouse heating purposes, or after proper treatment to avoid spread of any pest and disease, as admixtures for substrates or integrated in soils to improve soil characteristics. Another alternative to current waste management practices and carbon sequestration opportunity is the production of biochar (thermally converted biomass) from plant residues and use as a soil amendment. Dunlop et al. (2015) analysed the use of biochar produced with tomato plant feedstocks as a substrate for tomato hydroponic crops. Some institutions have already developed waste management solutions that could help to fix the C captured by plants and reduce resources depletion. Wageningen University has developed a technology to produce cardboard for packaging with tomato plants stems and leaves (Wageningen UR, 2014). Ford Motor Company, in collaboration with Heinz ketchup, is developing new bio-composites based on tomato processing wastes (Ford Motor Company, 2014). Moreover, the Biocopac Project has developed bio-resins based on tomato processing wastes to cover the inside part of food cans (Biocopac Project, 2013). The above can serve as good examples for clustering (see next section) greenhouse facilities with different industries to reach the sustainability goals. Nevertheless, a bottleneck to crop residues use may be the low quantity of crop residues produced per greenhouse unit, something that means that in order to explore the use of crop residues in relative processes like biogas production, composting, biochar and other, clustering of greenhouse units may be necessary.

4. Clustering in protected horticulture to increase circularity

The concept of agroparks (spatial cluster of agricultural related functions aiming to apply the principles of industrial ecology in the agro-sector) emerged as a sustainable solution to many environmental and socio-economic problems. Clusters create new value chains and, in theory, they offer a variety of economic advantages as well as environmental benefits such as the reduction of transportation cost and the recycling of production residuals and wastes resulting in significant increase of circularity within the cluster. Moreover, through intelligent design and controlled production systems with closed material and energy loops, random effects of nature and waste of resources are minimized. The challenge is to make the total benefits of the cluster higher than the sum of individual firms.

Although in many cases (e.g. Almeria-Spain, Sicily-Italy, Westland, Aalsmeer and Venlo-The Netherlands) protected cultivation facilities are in clusters of farms, the advantages of clustering different industries in the format of an agricultural-industrial estate, in order to meet sustainability goals (sharing resources and reusing waste), social advantages (maintaining activity) and higher economic efficiency, have not been yet fully considered.

funded by European Commission

The Euphoros project (deliverable 22) presented the advantages of clustering greenhouses with paper and polyethylene industries and waste-paper and plastics management companies. They concluded that greenhouse clustering has proven to be an interesting approach in terms of environmental, economic and social sustainability.

Greenhouses could be also clustered with industries storing/producing CO_2 or waste heat, to be used for greenhouse CO_2 enrichment and heating, respectively. Another example of high circularity may be considered that of combined heat and power or cogeneration system in greenhouses that provides electrical power, heat and CO_2. Surplus power and heat is often sold into the local electricity grid and for district heating while the CO_2 released in the exhaust gases of the engine is used to promote plant growth. The above system has been successfully applied in the Dutch greenhouses and only in few cases in other locations. Yet, fair solutions based on local needs, resources and capacities, creating equal and sustainable markets have not been fully explored in different locations and conditions.

Another example of clustering may be considered that of urban agriculture. One of the multiple urban agriculture typologies consists of installing greenhouses on the top of buildings (rooftop greenhouses) or plant production units (plant factories) inside buildings. Rooftop greenhouses and plant factories can be integrated with buildings to exchange energy, water and CO_2 (from human respiration) flows and increase system efficiency. These systems allow an intensive food production, which will generate organic wastes that could be used to produce new products. Sanyé-Mengual et al. (2015) presented an environmental and economic life cycle assessment of rooftop greenhouses (RTGs). They fund that a change from the current linear system to the RTG system could result in a reduction, per kilogram of tomatoes, in the range of 44.4–75.5% for the different impact categories analysed, and savings of up to 73.5% in energy requirements.

5. Success factors and barriers for circularity

Stakeholders: Protected horticulture has an extensive range of stakeholders and their presence in each region and active involvement and cooperation in the sector, at different levels and with different roles and interests, is necessary for the increase in circularity in protected cultivation. Main (direct and indirect) stakeholders in protected cultivation include greenhouse design and construction companies, horticultural farm input suppliers, ICT companies, greenhouse advisors, horticultural associations, agri-food processing and marketing chains, retailers, supermarkets, consumers, researchers, policy makers, governments and non-governmental organisations. Effective communication between stakeholders is not only required in the development and introduction of technologies that will increase circularity in protected cultivation systems, but also throughout the ongoing use of these technologies.

Level of technology and farm size: The degree of circularity of protected cultivation, among others, depends also on the level of the technological advances used in the greenhouse system but a trade off between the technology and the workforce needed in high or low tech greenhouses to reach a certain level of circularity. Hi-tech greenhouses may present high level of circularity but need high investment cost, while in low-tech (low investment cost) greenhouses, to reach a certain level of circularity is more labour intensive.

Soilless cultivation systems and especially closed or re-circulating hydroponic systems can significantly reduce fertilizer run-off but not eliminate it, and the spent nutrient solution has to be ultimately collected and treated at the end of the crop cycle. Also, closed systems involve greater installation and running costs, need a high degree of automation and technical skill, and their economic viability is a question of debate in southern Europe horticulture. As a consequence, the majority of the high-value horticultural production in Mediterranean countries is done using 'open' systems. Muñoz et al. (2012) presented an alternative way to reduce fertilizer use and, hence, reduce the pollution potential of leachate in soilless crops by collecting and re-using it for a secondary (greenhouse or open field) crop. Their results showed that the nitrogen balance for the two combined systems showed an important decrease in N leachate. The adoption of the 'cascade' crop system reduced environmental impact for climate change category by 21%, but increased eutrophication category by 10% because of the yield reduction.

In addition, greenhouse units with small total *size* (e.g. less than 0.5 ha), which can be found in several regions around the Mediterranean, are not equipped with advanced climate and fertigation control systems, due to the high cost of the relative equipment. Advanced *climate and fertigation control systems and decision* *support systems* (DSS) are important tools to control the inputs and outputs of the greenhouse system and significantly affect the degree of circularity obtained. In addition, the advanced use of data to enhance the optimal use of inputs and growing environment increases the potential to grow more organic. However, currently DSSs are not extensively used. In many cases, growers and advisors consider the available DSSs to be too complex and lacking easy-to-use interfaces. In the case that relative controllers and DSS are available, the application of closed soilless cultivation systems is possible. Nevertheless, commercial application of closed soilless cultivation systems is scarce, as their management is more difficult compared with open (free-drainage) cultivation systems. Reuse of this drainage solution is associated with the risk of pathogen propagation throughout the Fertigation-system and strongly aggravates the salt accumulation in the root zone, which makes the management of closed systems difficult. The installation of nutrient solution recycling systems (closed Fertigation) is associated with high investment costs and maintenance efforts and does not conclusively solve the problem of salt accumulation.

Water quality: to obtain a high degree of circularity for water and nutrients it is crucial that the water used for irrigation is of high quality. If the water used contains solutes that are not absorbed by the plants (e.g. Na or Cl), then continuous reuse of the drainage solution in closed hydroponic systems will result in salt accumulation. Therefore, many greenhouse growers operate open fertigation systems, i.e. are not recycling nutrient solutions. This practise of discharging used nutrient solutions as waste water entails severe environmental problems and is a waste of water and fertilizers.

Location: Optimal solutions for circularity have not been developed for all regions around Europe or the Mediterranean. For example, the closed or semi-closed greenhouse concept that has been developed and is applied in the case of some Dutch greenhouses cannot be directly transferred to the Mediterranean regions since the main challenge to operate a closed/semi-closed greenhouse under subtropical climatic conditions is the large cooling requirement. Another example is that of the DSS developed: fertilization needs for soilless crops have been mainly studied in Central and North EU conditions but cannot be directly applied for South EU regions since the climate conditions between the different locations are much different and thus water and nutrient needs may differ significantly (Schwarz et al., 2001; Medrano et al., 2005). Another factor affecting the level of circularity may be the crop cycle. Depending on the market prices, the equipment of the greenhouse and the outside climate conditions, the total cultivation period per year and the crop cycle may be much different between the different regions. In spite of a widespread perception to the contrary, the length of the growing cycle has no direct effect on WUE, since both production and crop transpiration are highly correlated to the radiation cumulated in the period. It is true, however, that usually a longer growing cycle results in a higher harvest index, which has some effect on WUE. Obviously, the quality of the installations and the crop-management skills may greatly affect WUE, but it has been shown (Katsoulas et al. 2015) that the need for ventilation in various climates is probably the largest single cause of differences among WUE values.

Extension services – knowledge transfer: In order to increase circularity in protected cultivation, successful and sustainable adaptation of the current systems, supported by appropriate technologies is required. Experience has highlighted the need for collaboration, communication, and contextual appreciation to ensure that the technologies introduced are appropriate. The adoption of agricultural adaptation technologies can be strengthened by strategic marketing approaches that are based on the values and priorities of the target audience. Extensive training, communication and extension programmes, public awareness about sustainable development principles can be used for capacity-building to target increase of circularity in protected cultivation. Ongoing support for the end users should be provided to ensure informed and progressive problem-solving and, understanding, which may contribute to the sustainability of a technology.

6. Discussion questions

- Which are the most important resources/products/by-products/waste that could (or need to) be recirculated to increase circularity in protected cultivation systems? Could you indicate additional resources/products/by-products/waste that could be recirculated and are not referred herein?
- Are there available technologies, management strategies, cooperation models and techniques that could increase circularity in protected cultivation?

funded by European Commission

- Which are good practice examples of highly circular protected cultivation systems (including organic)?
- What are the bottlenecks for adopting good practice examples of highly circular systems in the EU?
- Which are the success factors of best practice examples of highly circular systems?
- Which are the knowledge requirements and crucial partnerships to implement best practice examples?
- Which are the technical or economic barriers for the extension of application and use of highly circular systems all around EU?
- Which are the adaptation techniques that need to be developed to increase circularity?
- Which are the knowledge (technical, practical, scientific) gaps and further research needs from practice that need to be covered in order to increase circularity in protected horticulture?

7. Reference List

Adapt2Change. Adapt agricultural production to climate change and limited water supply. https://www.adapt2change.eu (accessed 29/09/2017)

Biocopac Project, 2013. Biocopac, Development of bio-based boating from tomato processing wastes intended for metal packaging. (Available on line: http://www.biocopac.eu/en/, accessed 16/10/2017).

Callejón-Ferre, A.J., Velázquez-Martí, B., López-Martínez, J.A., Manzano-Agugliaro, F., 2011. Greenhouse crop residues: Energy potential and models for the prediction of their higher heating value. Renewable and Sustainable Energy Reviews, 5(2), 948-955.

Carranca, C., Martínez-Gaitán, C.C., 2014. Mini-paper - Nitrogen and water need based on a model. Focus Group Fertiliser efficiency in horticulture, EIP-AGRI, 5 p. (available online: http://ec.europa.eu/eip/agriculture/sites/agri-eip/files/7_mini-paper_n_and_water_models.pdf, accessed 16/10/2017).

De Gelder, A., Dieleman, J.A., Bot, G.P.A., Marcelis, L.F.M., 2012. An overview of climate and crop yield in closed greenhouses. J. Hortic. Sci. Biotech. 87(3), 193-202.

Dunlop, S.J., Arbestain, M.C., Bishop, P.A., Wargent, J.J., 2015. Closing the loop: use of biochar produced from tomato crop green waste as a substrate for soilless, hydroponic tomato production. HortScience 50, 1572–1581.

EU Aquaponics Hub. Realising Sustainable Integrated Fish and Vegetable Production for the EU https://euaquaponicshub.com/, http://www.cost.eu/COST_Actions/fa/FA1305, (accessed 29/09/2017)

Euphoros. Efficient use of inputs in protected horticulture. http://www.wur.nl/en/Research-Results/Projects-and-programmes/Euphoros-1.htm, (accessed 29/09/2017).

Euvrin. European Vegetables Research Institutes Network. http://euvrin.eu (accessed 29/09/2017).

FAO, 2009. How to Feed the World in 2050. www.fao.org (http://www.fao.org/fileadmin/templates/wsfs/docs/expert_paper/How_to_Feed_the_World_in_2050.pdf, accessed 29/09/2017).

Fertinnowa. Transfer of INNOvative techniques for sustainable WAter use in FERtigated crops. http://www.fertinnowa.com, (accessed 29/09/2017)

Ford Motor Company, 2014. You Say Tomato; We Say Tom-Auto: Ford and Heinz Collaborate on Sustainable Materials for Vehicles. Ford Media Center (available online: https://media.ford.com/content/fordmedia/fna/us/en/news/2014/06/10/ford-and-heinz-collaborate-on-sustainable-materials-for-vehicles.html, accessed 16/10/2017).

Gallardo, M., Fernández, M.D., Giménez, C., Padilla, F.M., Thompson, R.B., 2016. Revised VegSyst model to calculate dry matter production, critical N uptake and ETc of several vegetable species grown in Mediterranean greenhouses. Agricultural systems, 146, 30-43.

Katsoulas, N., Bartzanas, T., Kittas, C., 2017. Online professional irrigation scheduling system for greenhouse crops. Acta Horticulturae, 1154, 221-228.

Katsoulas, N., Sapounas, A., De Zwart, F., Dieleman, J.A., Stanghellini, C., 2015. Reducing ventilation requirements in semi-closed greenhouses increases water use efficiency. Agricultural Water Management, 156, 90-99.

Körner, O., Gutzmann, E., Kledal, P.R., 2017. A dynamic model simulating the symbiotic effects in aquaponic systems. Acta Horticulturae, 1170, 309-316.

Medrano, E., Lorenzo, P., Sánchez-Guerrero, M.C., García, M.L., Caparrós, I., Coelho, G. and Giménez, M., 2005. Water and nutrient use efficiency of a tomato crop as affected by two refrigeration methods: external mobile shading and fog system. Acta Hortic. 697, 463-467.

Montero, J.I., Antón, A., Torrellas, M., Ruijs, R., Vermeulen, P., 2011. Environmental and economic profile of present greenhouse production systems in Europe. Annex. EUPHOROS project Deliverable no.: 5 Annex Public. (http://www.wur.nl/en/Research-Results/Projects-and-programmes/Euphoros-1/Reports.htm, accessed 29/09/2017).

Muñoz, P., Flores, J.S., Antón, A., Montero, J.I., 2017. Combination of greenhouse and open-field crop fertigation can increase sustainability of horticultural crops in the Mediterranean region. Acta Horticulturae, 1170, 627-633.

Muñoz, P., Paranjpe, A., Montero, J.I., Antón, A., 2012. Cascade crops: An alternative solution for increasing sustainability of greenhouse tomato crops in Mediterranean zone. Acta Horticulturae, 927, 801-805.

OrganicGH. Towards a sustainable and productive EU organic greenhouse horticulture. COST Action FA1105 BioGreenhouse http://www.wur.nl/en/Expertise-Services/Research-Institutes/plant-research/Greenhouse-Horticulture/news-calendar-greenhouse/BioGreenhouse.htm, http://www.cost.eu/COST_Actions/fa/FA1105 (accessed 29/09/2017).

Reinoso Moreno, J.V., Fernandez Fernandez, M.D., Sanchez Molina, J.A., Lopez Hernandez, J.C., Acien Fernandez, F.G., 2017. Processing of crop residues for heating and CO2 enrichment in greenhouses. 6th World Congress on Biofuels and Bioenergy September 05-06, 2017, London, UK (https://doi.org/10.4172/2155-6199-C1-009).

Santamaria, P., Campanile, G., Parente, A., Elia, A., 2003. Subirrigation vs drip-irrigation: effects on yield and quality of soilless grown cherry tomato. J. Hortic. Sci. Biotech. 78, 290–296.

Sanyé-Mengual, E., Oliver-Solà, J., Montero, J.I. Rieradevall, J., 2015. An environmental and economic life cycle assessment of rooftop greenhouse (RTG) implementation in Barcelona, Spain. Assessing new forms of urban agriculture from the greenhouse structure to the final product level. Int J Life Cycle Assess, 20: 350. https://doi.org/10.1007/s11367-014-0836-9

Schwarz, D., Kläring H. P., Ingram K. T., Hung Y. C. (2001). Model-based control of nutrient solution concentration influences tomato growth and fruit quality. J. Am. Soc. Hortic. Sci. 126, 778–784.

Stanghellini, C., Kempkes, F.L.K., Knies, P., 2003. Enhancing environmental quality in agricultural systems. Acta Horticulturae, 609, 277–283.

Thompson, R., Voogt, W., 2014, Optimal irrigation management is necessary for optimal nutrient management. Mini-paper - Irrigation management using soil moisture sensors. Focus Group Fertiliser efficiency in horticulture, EIP-AGRI, 8 p. (available online: http://ec.europa.eu/eip/agriculture/sites/agri-eip/files/6_mini-paper_soil_moisture_sensors_0.pdf, accessed 16/10/2017).

Torrellas, M., Antón, A., Ruijs, M., García Victoria, N., Stanghellini, C., Montero, J.I., 2012. Environmental and economic assessment of protected crops in four European scenarios, In Journal of Cleaner Production, 28, 45-55.

Valenzano, V., Parente, A., Serio, F., Santamaria, P., 2008. Effect of growing system and cultivar on yield and water-use efficiency of greenhouse-grown tomato. J. Hortic. Sci. Biotech. 83(1), 71-75.

Vanthoor, B.H.E., Stigter, J.D., van Henten, E., Stanghellini, C., de Visser, P.H.B., Hemming, S., 2012. A methodology for model-based greenhouse design: Part 5, greenhouse design optimisation for southern-Spanish and Dutch conditions. Biosystems Engineering, 111, 350-368.

Vermeulen, P.C.M., 2008. Kwantitatieve informatie voor de glastuinbouw. Wageningen UR Glastuinbouw, Wageningen.

Voogt, W., Swinkels, G.-.J., van Os, E., 2012. Waterstreams: a model for estimation of crop water demand, water supply, salt accumulation and discharge for soilless crops. Acta Horticulturae, 957, 123-130.

Wageningen UR, 2014. Paper and cardboard made with tomato – Wageningen UR. (Available online: http://www.wur.nl/en/Expertise-Services/Research-Institutes/food-biobased-research/Expertise-areas/Biobased-materials/show/Paper-and-cardboard.htm, accessed 16/10/2017).

funded by European Commission

8. Annex 1. Statistics on protected cultivation in the EU

Table A1.1. Areas (in ha) under cover cultivated with vegetables, flowers and permanent crops (source: Eurostat 2017).

TIME / GEO	2005	2007	2010	2013
Belgium	2,140	2,120	2,060	1,800
Bulgaria	900	1,140	1,090	1,080
Czech Republic	180	190	0	0
Denmark	450	470	460	400
Germany	3,370	3,430	3,170	3,110
Estonia	60	60	40	40
Ireland	60	30	60	180
Greece	4,670	5,340	4,290	4,730
Spain	52,170	52,720	45,700	45,200
France	9,620	9,790	:	11,190
Croatia	:	250	410	500
Italy	28,640	26,500	39,100	38,910
Cyprus	420	430	450	420
Latvia	110	80	50	40
Lithuania	1,010	450	310	330
Luxembourg	0	10	0	0
Hungary	1,910	1,760	1,960	2,260
Malta	70	70	80	100
Netherlands	10,540	10,370	9,820	9,330
Austria	290	580	620	720
Poland	7,170	7,560	6,630	8,080
Portugal	2,310	2,220	2,360	2,490
Romania	2,790	3,250	3,020	3,300
Slovenia	170	180	170	160
Slovakia	250	190	150	100
Finland	450	440	420	400
Sweden	420	180	200	260
United Kingdom	1,650	1,790	1,560	2,420
Iceland	:	:	20	:
Norway	180	180	160	140
Switzerland	750	780	770	:
Montenegro	:	:	50	:

Table A1.2. Number of holdings/farms under cover with vegetables, flowers and permanent crops (source: Eurostat 2017).

TIME ▸ / GEO ▾	2005	2007	2010	2013
Belgium	3,690	3,380	2,850	1,420
Bulgaria	7,750	7,730	6,720	6,040
Czech Republic	840	580	0	0
Denmark	730	720	840	700
Germany	9,980	8,920	6,570	5,770
Estonia	700	380	240	190
Ireland	380	270	180	170
Greece	10,240	12,150	8,890	9,180
Spain	32,510	30,460	23,610	21,680
France	15,350	13,850	:	13,860
Croatia	:	1,550	2,560	2,990
Italy	31,080	26,650	32,720	28,270
Cyprus	670	650	570	530
Latvia	320	420	260	340
Lithuania	34,850	11,890	10,000	9,770
Luxembourg	30	30	10	10
Hungary	12,050	8,760	9,430	13,950
Malta	290	300	280	310
Netherlands	8,600	7,410	4,980	4,120
Austria	700	1,450	1,400	1,480
Poland	29,370	24,530	14,880	16,120
Portugal	4,110	3,770	3,700	5,340
Romania	18,630	16,670	17,970	19,570
Slovenia	5,150	1,440	570	630
Slovakia	830	930	270	200
Finland	1,780	1,580	1,370	1,270
Sweden	1,540	660	770	870
United Kingdom	5,170	3,740	2,640	2,350
Iceland	:	:	70	:
Norway	790	720	640	440
Switzerland	1,320	1,370	1,290	:
Montenegro	:	:	470	:

Table A1.3. Greenhouse area (in 1000 ha) covered by some major greenhouse crops in Europe during 2015 (source: Eurostat 2017).

CROPS ▸ / GEO ▾	Lettuces - under glas	Tomatoes - under gla	Cucumbers - under g	Peppers (capsicum)	Strawberries - under
European Union (28	12.04	41.56	14.76	:	19.97
Belgium	1.01	0.51	0.04	0.09	0.56
Bulgaria	0.10	0.39	0.41	0.08	0.00
Czech Republic	0.00(n)	0.00(n)	0.00(n)	0.00(n)	0.00(n)
Denmark	0.00	0.03	0.05	0.00(n)	0.00(n)
Germany	0.07	0.33	0.19	0.07	0.73
Estonia	0.00	0.00	0.00	0.00	0.00
Ireland	0.12	0.01	0.01	0.00(n)	0.17
Greece	0.65	2.64	1.19	0.94	1.13
Spain	1.04	19.41	7.44	12.42	7.06
France	2.39	2.03	0.53	:(z)	1.77
Croatia	0.04	0.14	0.04	0.07	0.07
Italy	3.84	7.44	0.59	2.44	3.23
Cyprus	0.00(n)	0.13	0.15	0.00(n)	0.00(n)
Latvia	0.00(n)	0.00(n)	0.00(n)	0.00(n)	0.00(n)
Lithuania	0.13	0.27	0.12	0.00(n)	0.00(n)
Luxembourg	0.00(p)	0.00(p)	0.00(p)	0.00(p)	0.00(p)
Hungary	0.10	0.20	0.10	:	0.10
Malta	0.00(n)	0.00(n)	0.00(n)	0.00(n)	0.00(n)
Netherlands	0.35	1.76	0.55	1.20	0.36
Austria	0.09	0.18	0.15	0.12	0.00(n)
Poland	0.40	3.10	1.60	1.70	0.20(e)
Portugal	0.96	0.98	0.19	0.05	0.07
Romania	0.06	1.65	1.23	0.47	0.00
Slovenia	0.00(n)	0.00(n)	0.00(n)	0.00(n)	0.00(n)
Slovakia	0.00	0.02	0.01	0.01	0.00
Finland	0.29	0.11	0.09	0.01	0.00
Sweden	0.06	0.04	0.09	0.00	0.05
United Kingdom	0.35	:(z)	0.00(n)	0.09	4.46
Iceland	0.00	0.01(e)	0.01(e)	0.01	0.00
Liechtenstein	:	:	:	:	:
Norway	0.01	0.03	0.02	:	0.00
Switzerland	0.14	0.18	0.08	0.02	0.15
Montenegro	0.00(n)	0.00(n)	0.00(n)	0.00(n)	0.00(n)
Former Yugoslav Rep	:(z)	:(z)	:(z)	:(z)	:(z)
Albania	0.07	1.19	0.39	0.23	:
Serbia	0.00(n)	0.00(n)	0.00(n)	0.00(n)	0.00(n)
Turkey	3.00	25.00	8.00	7.00	3.00
Bosnia and Herzegov	:(z)	:(z)	:(z)	:(z)	:(z)
Kosovo (under Unite	:	:	:	:	:

Table A1.4. Total production (1000 t) from some major greenhouse crops in Europe during 2015 (source: Eurostat 2017).

CROPS	Lettuces - under glas	Tomatoes - under gla	Cucumbers - under g	Peppers (capsicum)	Strawberries - under
GEO					
European Union (28	:	:	:	:	:
Belgium	43.39	253.05	16.85	25.48	:(z)
Bulgaria	1.66	50.11	41.38	2.78	0.04
Czech Republic	0.00(n)	0.00(n)	0.00(n)	0.00(n)	0.00(n)
Denmark	0.46	10.58	19.51	0.00(n)	0.00(n)
Germany	2.62	80.92	42.76	7.50	12.13
Estonia	0.00	0.90	5.40	0.00	0.00
Ireland	4.35	4.43	1.83	0.00(n)	5.79
Greece	14.25	326.40	115.43	88.22	58.76
Spain	27.62	1,835.31	685.19	898.29	394.43
France	61.81	589.32	121.11	:(z)	40.06
Croatia	1.50	25.17	3.84	2.89	0.88
Italy	124.37	516.29	34.73	96.63	:
Cyprus	0.00(n)	7.87	6.21	0.00(n)	0.00(n)
Latvia	0.20	6.10	6.40	0.00(n)	0.00(n)
Lithuania	1.48	6.55	10.10	0.00(n)	0.02
Luxembourg	0.00(p)	0.12(p)	0.05(p)	0.00(p)	0.00(p)
Hungary	:	:	:	:	:
Malta	0.00(n)	0.00(n)	0.00(n)	0.00(n)	0.00(n)
Netherlands	9.45	890.00	405.00	345.00	28.58
Austria	2.79	55.38	29.62	14.53	0.00(n)
Poland	16.00	553.20	266.70	129.50	9.80(e)
Portugal	29.63	29.63	9.61	3.00	2.74
Romania	1.42	79.41	56.07	14.38	0.02
Slovenia	0.00(n)	0.00(n)	0.00(n)	0.00(n)	0.00(n)
Slovakia	0.01	8.70	1.64	0.13	0.00
Finland	11.44	38.89	40.49	0.49	0.07
Sweden	2.42	14.79	28.04	0.03	0.83
United Kingdom	38.00	:(z)	0.00(n)	23.10	115.50
Iceland	0.00	0.14	0.18	0.01	0.00
Liechtenstein	:	:	:	:	:
Norway	:	:	:	:	:
Switzerland	:(z)	44.50(e)	14.00(e)	0.95(e)	:(z)
Montenegro	0.00(n)	0.00(n)	0.00(n)	0.50	0.00(n)
Former Yugoslav Rep	:(z)	:(z)	:(z)	:(z)	:(z)
Albania	0.60	103.20	38.80	16.80	:
Serbia	0.00(n)	0.00(n)	0.00(n)	0.00(n)	0.00(n)
Turkey	68.00	3,315.00	1,066.00	542.00	137.00
Bosnia and Herzegov	:(z)	:(z)	:(z)	:(z)	:(z)
Kosovo (under Unite	:	:	:	:	: