EIP-AGRI Focus Group

Circular horticulture

FINAL REPORT

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Table of contents

1. Executive summary

Protected Horticulture can ensure high quality production and contribute to global food security. Furthermore, protected horticulture (growing in greenhouses) provides significant opportunities for a more 'circular' production to use resources efficiently. This includes recycling, across different levels, from individual farms to regional level. Greenhouses can help support circularity because they have (i) potential for high productivity with reduced water and agrochemicals use per unit of production, (ii) a production capacity up to 10-15 times higher than open field-based agriculture per ha and (iii) great potential for the recycling of water and nutrients.

The Focus Group on 'Circular Horticulture – how to increase circularity in protected horticulture' was launched by the European Commission in Autumn 2017. The aim of this Focus Group was to look at examples of good practice of circularity in protected horticulture and how these could be transferred to other situations in Europe to benefit the wider sector. It also looked at success and fail factors for circular approaches in horticulture, identified knowledge gaps and possible future research needs. The group met twice, on 29-30 November 2017 (in Prague, Czech Republic) and on 18-19 April 2018 (in Den Hague, The Netherlands) to discuss how to increase circularity in protected horticulture.

A starting paper, written by the Focus Group's coordinating expert was written and circulated to all the experts prior to the first meeting.

At the end of the first meeting, the group selected the topics of the 'mini-papers' to be elaborated by the group. The topics selected were:

- Circularity and/or valorisation of biomass: crop residues, by-products and extraction of molecules.
- Clusters raising circular horticulture bioeconomy.
- Monitoring and metrics to boost circularity in horticulture.
- Awareness raising and transfer of knowledge and technology in circular horticulture.
- Water use in greenhouse horticulture: efficiency and circularity.

During the second meeting, the drafts of the mini-papers were presented and discussed. The aim of the second meeting was mainly to (i) identify needs from practice and propose further research topics and (ii) identify ideas for Operational Groups (OGs).

Some of the ideas identified by the Focus Group for future OGs in the area of horticulture were:

- alternative and renewable growing media
- rainwater storage
- mixed farming systems and bio digestion of manure and use of bio gas for heat production
- urban farming
- documenting experiences related to circularity in protected cultivation systems- 'Seeing is believing'
- support data analysis and focus on the development and evaluation of indicators of greenhouse systems performance
- finding ways for farmers to cooperate, for instance in logistics of biomass/vegetables

The recommendations for research topics in the area of horticulture include several aspects mentioned as topics for the OGs but also some specific issues such as:

- social / economic science approach to circularity, i.e. looking at consumer views on circular horticulture, and their role in supporting the development of circularity in the sector
- dynamic biomass streams: biomass mapping of the main European products, analysing the logistics, streams, potential and risks
- development of new and adapted crops
- low cost technology solutions for water and nutrient measurements
- alternative constituents for growing media
- novel and economic or low-cost solutions for water storage
- biodegradable materials for greenhouses

The examples of practical solutions are based on existing practices tested by groups of farmers, researchers, advisers and others who, in different formats, have worked together to developed innovations.

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The next step for the Focus Group is the dissemination of its results and recommendations through the EIP-AGRI network and by each Focus Group expert. All experts are willing to cooperate at local level by spreading the knowledge gained and also by supporting the setting-up of local Operational Groups under Rural Development programmes.

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2. Introduction

The challenges to feed the world and at the same time meeting increasing demands for non-food products or the delivery of public goods are becoming clearer. Depending on the situation in various parts of the world, they call for stabilising or increasing production with a decrease in inputs, higher resource use efficiency, minimum or zero effect on the environment in line with sustainability principles.

Protected horticulture can ensure high quality production and contribute to global food security. Furthermore it provides many opportunities for a more 'circular' production to use resources more efficiently, including recycling, across different levels, from individual farms to regional level. This is achieved by both simple and advanced techniques for farm, crop management, precise application of resources (water, fertilisers, energy), so that environmental and climate impact can be controlled and the use of resources optimised.

Greenhouses are particularly linked to circularity due to:

- their potential for high productivity with reduced water and agrochemicals use per unit of production
- their production capacity up to 15 times higher than open field-based agriculture per ha
- their high potential for the recycling of water and nutrients

The Focus Group on "Circular Horticulture – focus on how to increase circularity in protected horticulture" was launched by the European Commission in 2017 as part of the activities carried out under the European Innovation Partnership for Agricultural Productivity and Sustainability (EIP-AGRI).

Aim of this Focus Group was to look at examples of good practice of circularity in protected horticulture and how these could be transferred to other situations to benefit the wider sector. It also looked at success and fail factors for circular approaches in horticulture, identified knowledge gaps and possible future research needs with practical impact.

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3. Brief description of the process

The Focus Group was established in Autumn 2017. The 20 members (**Annex 1**) were selected by EIP-AGRI from a number of applicants from both research and practice throughout Europe. The group met twice, in November 2017 (in Prague, Czech Republic) and April 2018 (in The Hague, The Netherlands) to discuss how to increase circularity in protected horticulture.

A starting paper, written by the Coordinating Expert, was written and circulated to all the experts prior to the first meeting. The starting paper and the presentation carried out by the Coordinating Expert during the first meeting served as a basis for the experts' work. It presented several best practice examples and possibilities for circularity in water, nutrients, growing media, plastics, paper and biomass. It also presented the opportunities for circularity which come from the clustering of greenhouses with other facilities and factories linking with the inputs or outputs of the greenhouse ecosystem. In addition, the starting paper presented the success factors and barriers for circularity in protected cultivation systems.

During the first meeting, experts presented some selected best practice examples of highly circular systems in protected cultivation systems. At the end of the first meeting, the group developed a short list of specific topics that were to be further discussed. These topics were then elaborated in 'mini-papers', produced mainly in between the two meetings.

During the second meeting, the findings of the mini-paper sub-groups were presented and discussed. The second meeting mainly focused on:

- identifying needs from practice and proposing directions for further research
- identifying ideas for Operational Groups.

All the documents produced by the Focus Group can be found on the **EIP-AGRI website**.

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4. Context and state of play

4.1. Framing key issues

4.1.1. Potential for circularity in protected cultivation systems

The total area of protected cultivation is steadily increasing in the EU. In 2015 the estimated total area in the EU was about 175000 ha[1], and the rate of increase was close to 4.5% between 2005 and 2013. In the Mediterranean region, protected cultivation constitutes the most productive form of primary agricultural production, a total area of about 120000 ha was recorded in 2016 (statistics - see **Annex 4**). The Netherlands and Spain are greenhouse hotspots but other countries including Italy, France and Greece are expanding their industries (Figure 1). The main crops cultivated are vegetables (with tomato and cucumber covering almost 70% of the cultivated area), cut flowers and potted plants.

Figure 1. Distribution of greenhouse covered areas in EU countries

Some of the reasons leading to an increase of protected cultivation are:

- greenhouses can ensure high resource use efficiency and provide high-quality products all-year round
- outside climate conditions are extreme and unpredictable as a result of climate change, whereas greenhouses can disconnect, to some degree, the internal and external climate conditions
- water shortage, which is critical especially in Mediterranean countries
- environmental pollution & food security problems

[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.

Greenhouse structures and equipment differ greatly around the EU depending on the climate conditions, the technologies and the workforce available in the region. Other factors that play an important role are: the specific crop cultivated, marketing issues and the funding of the greenhouse units.

The majority of greenhouses in the Mediterranean area are low cost, low-tech, labour intensive and rudimentarily equipped. In Central and North Europe, greenhouse units are mainly high-tech and demand a higher investment cost per square metre, they tend to cover larger areas and require less labour. In both systems, most of the greenhouse crops are grown in the soil but in recent decades, there has been a switch to soilless production systems in conventional agriculture. Hydroponic systems offer several benefits such as the control of soilborne pathogens, superiority of physical and hydraulic characteristics of growing media, better control of nutrient availability, pollution prevention and higher water and nutrients use efficiency.

Although high-tech greenhouses are capable of providing the optimal conditions for year-round production, they are the most expensive option in terms of capital, running costs and energy consumption. Vanthoor et al. (2012) reported that the most profitable infrastructure for a specific region is not necessarily the most expensive and growers' experiences show that in many cases high profits can also be achieved using intermediate-level greenhouses or low cost structures[2]. Labour costs also have to be taken into account as a variable. The technology and automation is compensating high labour costs and vice versa.

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. An approximation of the average cost structure of a 10 ha high-tech and low-tech greenhouse would be from 9 to 12 million Euros and from 2 to 6 million Euros, respectively. Growers with low-tech, simple greenhouses (i.e. Spanish parral or tunnel) have less to lose when tomato prices go down, unlike their Dutch counterparts with expensive modern greenhouses. On the other hand, the income of Spanish growers is more influenced by climate variations. Indeed, best practices and techniques in one location (e.g. Dutch greenhouses) are not necessarily profitable in other locations (South Spain or Portugal).

Protected cultivation and especially high-tech greenhouses and soilless cropping systems are very resource-intensive compared to open field soil cultivation. A rough estimation of some indicative average values for resources (external inputs) use for a year-round soilless tomato crop may be as follows:

- water: 1.5-1.8m^3/m^2/year
- fertilisers: 1.8-3.2kg/m^2/year
- energy for heating: 750MJ/m^2/year
- substrate: 20L/m^2/year
- plastics for greenhouse and soil covering: 0.18kg/m^2/year
- paper for packaging: 2.8kg/m^2/year

The Circular Economy is defined as an economic system that replaces the 'end-of-life' concept with restoration, a shift towards the use of renewable energy, eliminating the use of toxic chemicals (which impair reuse) and eliminating waste. It aims to achieve this through the superior design of materials, products, systems; with a final goal of changing the business models of companies completely.

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. However, this only holds true when greenhouse management is adequate and when precise irrigation and fertigation practices are implemented to minimise overexploitation and pollution of surface and ground water resources. Thus, although zero losses are close to being achieved for water and nutrients in high-tech greenhouses, this is not the case in low-tech greenhouses. Low-tech greenhouses are largely not circular for the moment because they have not optimised their nutrient flows and they do not have a high rate of recycling. Nevertheless, compared to open field cultivation, protected cultivation can decrease irrigation water requirements by reduced evaporation inside the greenhouse. Moreover, higher yields per square metre are usually achieved in greenhouses compared to outdoors, which also increases crop water use efficiency. Increased efficiency of the use of natural resources is at the centre of financial decision-making and practice to ensure added-value and re-use of resources such as water and nutrients. The European Commission launched its circular economy package on 2 December 2015 (EU,

[2] see **Discussion paper of FG27**

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2016) which includes developing quality standards for recycled nutrients/fertilisers and re-use of treated wastewater.

Prior to the first Focus Group meeting, a survey on circular economy was carried out among the experts of this Focus Group and the results were presented during the first meeting. The experts considered that the most important resource, by-product or waste for circulation or recycling purposes is water, followed by nutrients and fertilisers and then the crop residues, growing media, plastic, greenhouse frames, glass and lastly, paper (Figure 2a). Other things were also mentioned as important to circulate such as wasted packaging, fertiliser bags, polypropylene strings, liquid wastes (fertiliser solution, biocide, etc) and energy.

The experts were also asked what they considered easy and difficult to circulate, it was found that water is very important and halfway between easy and difficult (Figure 2b). Crop residues recycling is considered important and easy. On some other subjects there are differences between northern and southern regions. In the south there is no issue on glass recycling because there are almost no glass greenhouses. Fig 2c shows the "quadrant" of issues being considered both important and easy to solve. It was also noted that the main difficulty is the transfer of knowledge to the growers. In addition, the experts noted that growers do not see the need for using less water because the water is almost free.

The graphs below show the results of experts' opinions in more detail. -Top left are the resources experts considered most important to be (re)circulated in order to increase circularity in protected cultivation systems and on the top right the ones more difficult or easy to be (re)circulated from the greenhouse grower perspective. Bottom left is a mapping of difficult/important and easy/not important resources/by-products/waste for (re)circulation and bottom right are the priority factors considered to enhance or hinder the level of circularity in protected cultivation systems.

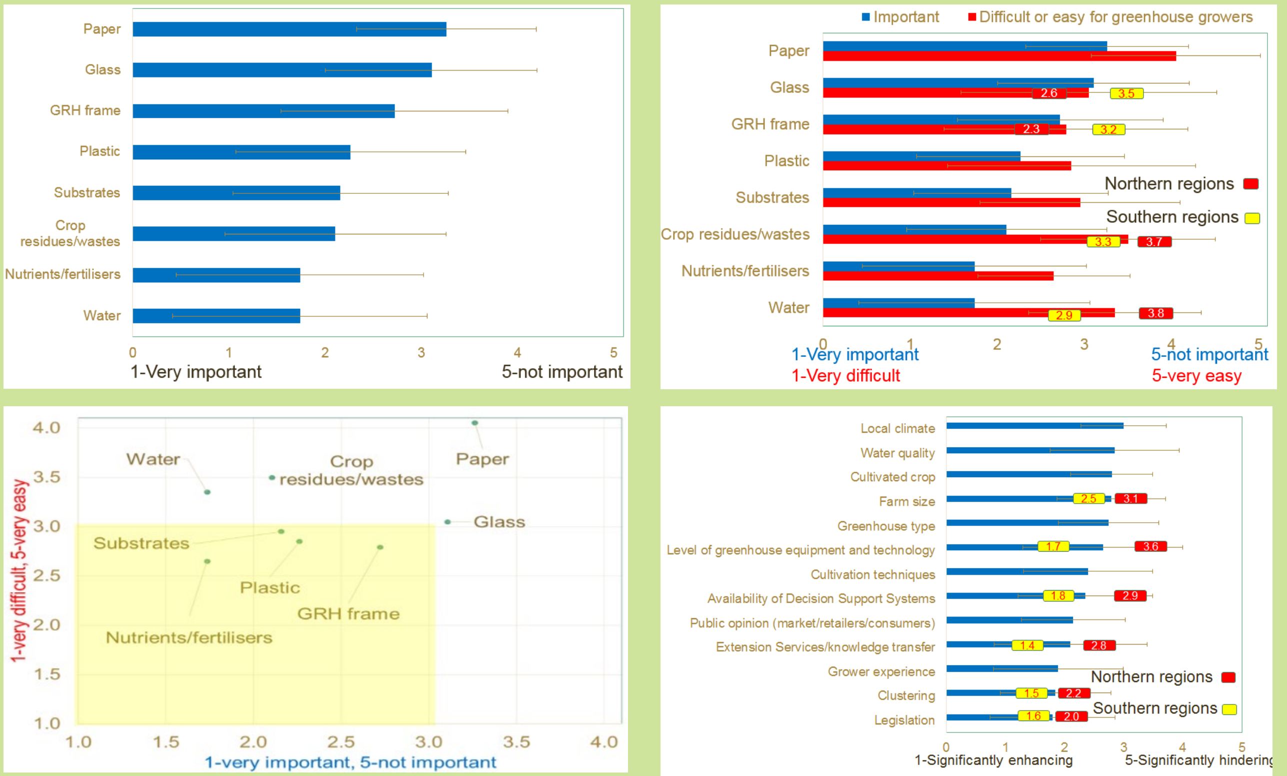

Figure 1. Focus Group Experts' opinion on (re)circulation of resources/by-products/waste

Currently, the degree of circularity of 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 limited possibilities for reuse of used artificial growing media represent one of the weak points of hydroponic technology in greenhouse and nursery production with regard to circularity. In most of the cases, used growing media, used plastic covers and crop biomass waste are disposed to landfill.

Horticultural biomass has a high potential for circularity. One example for the vast amount of biomass produced alongside a crop comes from tomato production. In 2016, tomato in Europe were harvested on an area of about 265 000 ha (EU-28; FAO, 2016), which generated an estimated biomass stream of almost 13 million metric tons. However, some problems for the reuse of greenhouse tomato plant biomass may occur due to the plastic strings and clips in the bio-waste, which may be costly to remove. This biomass compost cannot be easily used in growing media blends due to problems with high electrical conductivity and pH, but there are some high-tech and low-tech solutions. Depending on the location of production, these solutions can be realised by growers and farmers on-site, but the need of high financial investments or high specialisation can lead to off-site solutions that need off-site partnerships and careful transport planning.

Three different kinds of potential uses for biomass streams in general are identified and categorised in descending order of potential value:

1. nutritional/pharmaceutical use
2. material use
3. energy use

In all cases, the seasonal availability of the biomass streams, heterogeneity of the material as well as possible accumulation of contaminants including chemical plant protection residues and nutrients must be taken into consideration. Examples for good practice in each category are presented below in section 5.2 of this report.

4.2. Good practice examples of circular protected horticultural systems

Greenhouse crops in Mediterranean regions are usually over-irrigated with an excess of about 40% of nutrient solution containing not only fertilisers but also agrochemical residues. If 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.

Sensors for soil moisture and substrate water content can enhance water and nutrient management by ensuring that crops have an adequate amount of water and by limiting drainage thereby ensuring minimal nutrient leaching loss. Nevertheless, this has to be considered in relation to water quality: a low drainage rate in the case of irrigation with low quality water may lead to salinification. Decision Support Systems (DSS) provide customised recommendations for water and fertilisation or irrigation management that are specific for individual crops, sites and conditions. The symbiotic growing of fish and vegetables in recirculating water systems is emerging as one of the most important areas of sustainable agriculture. The combined hydroponic and aquaculture system reduces overall water discharge and increases overall water use efficiency but there are still some perception problems that need to be addressed at the level of both greenhouse farmers and consumers.

Growing media used in protected cultivation are normally reused, recycled or discarded to the environment, the latter being a potential threat to the environment. The chance of reusing exhausted growing media depends on the physicochemical properties of the material as well as on the crop's sensitivity. The number of growing cycles for which a substrate can be reused depends on its nature and the type of crop and sometimes the genotype. Generally, inorganic growing media tend to last longer; perlite up to 2-3 years (or more if older substrate is regularly mixed with new substrate), rockwool more than 3 years. Organic growing media have a shorter life, up to 2 to 3 years at a maximum, due to low bio-stability. Where 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 organic growing media can be used as soil amendment, for example to improve poor physical properties of clay soil. It can be mixed with other growing media or recycled to develop another type of growing media. Finally, used growing media could also be used for the production of materials for other uses such as turning rockwool into bricks for houses or re-manufacturing it into horticultural or insulation rockwool. Exhausted perlite may be also formed into construction blocks.

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 of plastics in protected horticulture is very low and thus, the extensive use of plastic has resulted in a significant waste disposal problem. Opportunities for recycling of plastic have increased in recent years due to high oil prices that have resulted in increased prices for recycled plastics (polyethylene greenhouse covering films may need to be replaced every 3 to 4 years), as well as due to growing consumer interest in recycling. Mulching plastics represent a significant problem as they are more expensive to recycle because they have to be washed. Packing plastics can be also a major issue especially in the floriculture sector.

4.2.1. Good practice examples indicated for low-tech greenhouses

Good Practices were identified and discussed during the first meeting of this Focus Group, as presented below:

1. **Composting waste and used growing media to produce new substrate or production compost for other purposes.** Different greenhouse wastes can be composted and reused as growing media. There are examples of mixing different products for producing substrate. Attention must be given to risk assessment and quality of the input material. Crop residues can be composted or vermicomposted and then be used as an organic amendment. With that process, organic waste has economic value for the growers, especially if the composting is located in a centralised composting plant. The sectors where recycled substrate can be used depends on:
    a. the existing residues in the substrate (e.g. cannot be used on organic farms because of pesticide residues);
    b. the salinity of the water. It is not possible to use high salinity water in reused growing media which usually have already high salinity.

   Recycled substrate can be used anywhere. Bottlenecks are saturation levels in biochar and residues such as pesticides, other persistent components, plant diseases and electrical conductivity values. Diseases are eliminated during the thermophilic phase of composting. The level of pesticide residues can be reduced through integrated pest management (IPM) practices: using antagonists, no pesticides, working on the substrate-soil health, better and healthier plants, creating more resilience to the crops by breeding ... in short: by taking a comprehensive view at the whole system.

2. **Adjustment of the fertiliser dose.** In some situations these practices are necessary. A good example is to measure the nitrogen content in the plants to assess the nitrogen needs. Geographically, this can be applied everywhere. A bottleneck is that growers often do not make soil analysis themselves but rather need specialised laboratories to perform the analyses. There is a crucial role for advisers in translating the results of soil analyses into practical recommendations for the growers. Incentives could be to provide subsidies for the services of advisers or for specific equipment for measurements. This is already applied in Catalonia, with the use of good models tailored to local conditions to create awareness for farmers.

3. **Valorisation of unmarketable products and crop residues.** Harvest losses can be used for various purposes, such as cattle feed, provided it meets safety standards. Another option is the extraction of high value molecules from crop residues like antioxidants, pharmaceutical products, products for cosmetics and fibre industries. Fibre-rich by-products, rich in dietary fibre and bioactive compounds are valuable raw materials, especially since consumers prefer natural supplements, fearing that synthetic ingredients may be the source of toxicity. The remaining residues can be composted afterwards. Waste or residues of crop residues after extraction can be further mixed and formulated to create biostimulants or other growing compounds for plants. Due attention needs to be given to the composition of crop residues and the presence of contaminants such as pesticides, in particular for uses in products such as cosmetics. Care needs to be taken to ensure that the processing itself does not have a negative impact on the environment. Technology for processing exists but needs to be further developed for some products.

4. **Use of wool as substrate.** Some parts of wool that cannot be used in other industrial areas, may be used for mulching, either as coverage in pot plants or part of new substrate.

5. **Storage of rain water.** In the Netherlands storage of rain water is obligatory. In Almeria (Spain) rain water is usually mixed with well water. Bottlenecks for the storage of rainwater in the Spanish context are the high costs and the lack of space. Greenhouses are generally made of plastic and have almost flat roofs that make it impossible to collect the rain water. Furthermore, the rainfall pattern (a lot of rain in a short amount of time) can be a problem. Solutions could be to build collective collection

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storages, to build storages under the greenhouses or to store water in aquifers using small dams. Using rain water can be stimulated by increasing the water price.

6. **Energy saving by passive systems**. Excess heat appearing during the day can be stored in water tanks, stone walls and water walls to release the heat at night.

7. **Use of biodegradable and smart plastics.** Biodegradable plastics are commonly used for mulching, although expensive. There is a need to further look at Life Cycle Assessments to establish the difference between biodegradable and non-degradable plastics. New types of plastics are developed that are 'photo-selective' and help to have a better climate in the greenhouse with a better control of pests and diseases. They also have a longer lifespan than previous types of bio-plastics. Bio-degradable plastics have a short lifespan and are more expensive (3 times higher in Belgium). In the Netherlands the situation is different because the elimination of non-biodegradable plastic is very costly. Also other bio-degradable products such as wires/strings and clips for 'hanging' the crops exist. This can help when composting the crop residues.

4.2.2. Good practice examples indicated for high-tech greenhouses

Good practices were identified and discussed during the first meeting of the Focus Group, as presented below:

1. **Closed or semi-closed greenhouse.** The concept of closed or semi-closed greenhouse was one of the practices discussed. The key elements of these systems are heat pumps and heat exchangers and the fact that this type of greenhouse is usually equipped with energy saving systems and energy screens. Due to the high costs of investment and production, closed greenhouses are usually built for highly demanded/high value crops. The concept of a closed or semi-closed greenhouses is mainly applied in cold climates, where cooling is easier due to the cooler weather conditions. Bottlenecks for their application are the high cost of investment, the need for funding and the long period for the return on investment. If combined with integrated pest management practices, closed or semi-closed greenhouses could reduce the use of pesticides. Also, it could be seen positively by the growers if new, more profitable crops could be cultivated.

2. **Closed hydroponic systems.** Closed hydroponic systems were also presented as one of the good practices to increase circularity. The key elements presented were the water and fertiliser savings and the increased water and fertiliser use efficiency. The system can be applied to all sectors and geographical locations but it needs good quality water as an input, which in some cases means that desalination units need to be in place. Desalination units can be a problem if installed at farm level because of the disposal of the brine to the environment. To apply the hydroponic system in practice, high expertise in water and nutrient management are essential. If this expertise is missing, the effects may be negative on crop yield. The interest in closed hydroponic systems may increase with changes in legislation on water use and reuse or with increasing prices for water. Additionally, appropriate labelling/certification of products with low water and fertiliser use would probably increase the marketability of the products from hydroponic systems.

3. **Aquaponics.** Aquaponics was discussed by the Focus Group for its advantages in reducing the need for water and fertiliser in crop production and also for reducing the need for water in fish production. The key elements characterising a commercial system are the automations, the management of water filtration (including biological filters) between each stage of the system, and the need for expertise and experience to manage the system. The system can be applied to all regions/locations and is usually used for short cycle crops such as leafy vegetables. The bottlenecks discussed were related to the need for demonstration of large scale systems, since the cost for the investment may be significant. There is currently very little experience and no significant tradition on aquaponics in Europe, so further evidence is needed. Finally, market/consumer needs regarding the choice of fish species should be taken into account rather than focusing on species that are easy to cultivate in aquaponic systems.

4. **Integrated pest management (IPM).** IPM requires a careful consideration of all available plant protection methods and subsequent integration of appropriate measures to avoid the development of populations of harmful organisms, reduce the use of plant protection and other contentious products

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and reduce or minimise risks to human health and the environment. 'Integrated pest management' emphasises the growth of a healthy crop with the least possible disruption to agro-ecosystems and encourages natural pest control mechanisms. It requires taking a system's view on production in greenhouses. There are several measures and tools that have to be combined in IPM and extra measures have to be taken to avoid entrance and spread of harmful organisms into the greenhouse. IPM can be applied to all crop types and locations but in general there is a lack of crop specific guidelines. Another bottleneck mentioned for the application of IPM is the lack of experience by growers and advisers. Labelling the products as produced under IPM conditions would increase their marketability and would provide incentives for growers. IPM is recommended in both high and low tech greenhouses but in the case of low tech greenhouses the availability of preventive measures for plant protection are limited due to greenhouse construction limitations.

5. **Adaptive cover materials and biodegradable mulching materials.** Adaptive cover materials that can be applied as additional layers to the glass cover affect mainly the solar radiation entering the greenhouse and also the energy losses by the greenhouse. Biodegradable mulching materials can be used for greenhouse soil coverage without the need to be removed and collected at the end of the growth cycle. Both materials are characterised by their specific properties (light transmittance, life duration). Covering materials can be applied to all crop sectors (fruit, vegetables, ornamentals) and regions while mulching covers are designed for soil grown crops. Their use is limited by the high costs and in most cases their low durability in time.

6. **Metrics and Decision Support Systems (DSS).** Metrics, Models and DSSs are usually a common practice used in high-tech greenhouses. Key elements of DSS are sensors used for assessing parameters related to climate, crop, soil/substrate and inputs and outputs in a greenhouse. DSS are also characterised by a large quantity of data collected. DSS as a tool can be applied to all crop sectors and to all regions. However, there is a knowledge gap between growers and advisers regarding the use of the systems, and a perception by the growers that DSSs are like "black boxes", thus the process of data and advice generation not easy to understand. In addition, the experts consider that each crop may have different needs and that the systems are not adapted to each specific case. Growers need systems that would allow them to benchmark their performance and compare the results with the ones from other greenhouses. Another incentive identified is that growers could gain experience and knowledge through the use of the advice generated by a DSS.

7. **Rooftop greenhouses/vertical farming. The** key elements are the combination-clustering with buildings and the full control of inputs/outputs (especially for the case of vertical farming). The practice is usually applicable for cultivation of small size plants and short cycle crops (such as vegetables) in urban areas. The practice it is not always cost effective and the cost of investment is high. Additionally, roof top greenhouses may have a negative visual impact on the area. In the areas where the trend to consume local products is significant and if there is a demand for local production, growers could invest in this practice.

8. **Organic fertilisers (=non mineral).** A key element for this good practice is to produce the organic fertilisers close to the greenhouses so that there is no need for lengthy transportation, especially for non-liquid fertilisers. Organic fertilisers can be applied to all crops and to all regions. The most significant problems for their application are related to food safety, to the non-constant dynamic of nutrients release in the soil and the resulting complex management of crop fertilisation.

9. **Use of crop residues for biomass heating.** The key element is the local production of crop residues and the need for effective methods for collection and storage of crop residues. This practice is applied mainly in vegetable crops that produce significant volumes of residues and can be applied in regions with heating requirements. However, the disadvantages of this practice are: the crop biomass may not be available all year round which has to be taken into consideration if heating is needed for long periods of the year; the biomass contains low energy per unit weight (high water content of green waste); the material has to be dried (max. 20% water content); and there is a need for storage facilities. An incentive for the use of the practice is the low cost of the energy produced.

10. **Community services.** Greenhouses that have lighting systems and water storage facilities may be used for community services. They can offer stability to the electricity network by turning on or off the lights depending on the availability of electricity in the network. They can also act as buffer for water storage during periods of extreme rain, preventing possible flooding in the surrounding region. This practice can be applied close to urban areas where water storage is needed. However, turning off the light at times when plants need additional light may have negative effects on productivity. In addition, growers need to have a mind-set that would trigger an interest in providing community services.

4.2.3. Clustering in protected horticulture to increase circularity

Clusters can be considered as a powerful tool for the implementation of circularity to the current value chain. These structures are made up of a set of companies, activities, services and products that, when incorporated into a given value chain, allow for greater efficiency in the primary production stages, through a better management of inputs and wastes. Two types of relationships among partners in clusters can be defined: (i) exchange of "material" goods in a symbiotic approach, and (ii) exchange of "immaterial" goods e.g. knowledge. Geographical factors affect both types of cross-linking, exchange of "material" goods can be successful when companies are closely located.

Clusters offer a variety of economic advantages as well as environmental benefits such as the reduction of transportation costs and the recycling of production residues and waste. This results in a significant increase of levels of circularity within a given cluster.

Some advantages of clustering are highlighted below:

- Clusters combine resources and economies of scale boosting economic development
- Clusters are closely related to the value chain management, incorporating new processes, bioprocesses, practices and business models that can either feedback the primary links of the value chains or supply new value chains with new products or services.
- Clusters intend to integrate vertical value chains linking agricultural production, processing, packaging, logistics, storage and trade according to sustainable principles with horizontal value chains to establish synergistic benefits.
- The synergistic effect of managing producers of raw materials and companies into clusters is win-win for everyone
- By clustering, SMEs reach a size that facilitates their access to knowledge, innovation, technical infrastructures and new markets, as well as their participation in Research and development and innovation (R+D+I) projects and/or public-private partnerships.
- Clustering around the primary production value chain leads to savings in logistics and facilitates overcoming common administrative and legal barriers.
- Clusters would increase resilience and reduce vulnerability of production systems by diversifying business, incorporating R+D+I resources and reducing their dependency on fossil and non-renewable sources.
- Clusters can drastically reduce environmental footprints, thereby contributing to mitigating climate change, adapting value chains to more sustainable systems and considering the value of ecosystem services.

Although in many cases (e.g. Almeria-Spain, Sicily-Italy, Westland, Aalsmeer and Venlo-The Netherlands) protected cultivation facilities are embedded in clusters of farms, the advantages of clustering with industries to form "agricultural-industrial estates" have not yet been fully considered – in terms of meeting sustainability goals (sharing resources and reusing waste), social advantages (maintaining jobs/activity) or higher economic efficiency.

Good practice scenarios for clustering of greenhouses with other activities include:

- downstream from the greenhouse (i.e. an activity re-using an output from the greenhouse): water re-use, biomass and waste re-use, plastic recycling, by-products from greenhouse productions, aquaponics,…
- from greenhouse to greenhouse: recirculation, cascade systems, nutrient recycling, reusing spent-growing media by composting or biochar production, …
- upstream from greenhouse: the greenhouse re-using the outputs from another activity: compost, biochar, aquaponics, waste heat or CO_2; …

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In all these situations, there are a few defining elements for building clusters:

- specifications of the circulating element: quantity, quality, volume (including dead volume such as water in vegetal matters or volume of low-density materials), temporal availability around the year
- logistics of the circulation: flow and efficiency, buffering, storage.

There is no defining sector or production but there are some restrictions: some products pose a risk with certain types of clustering, for example the re-use of urban waste, because of sanitary problems, potential toxicity and heavy metals concentrations. In the case of aquaponics: the choice of production sector is important for the greenhouse but also for the fish production, a market is needed for both activities. The geographical dimension of the cluster is essential. Distance is always a limitation and, in some cases, there can be no distance at all for example the re-use of waste heat or CO_2. The positioning of greenhouses is also a land use/urbanism problem. There may be a need to relocate farming activities closer to urban areas: city centres (urban farming), distance to logistic centres, re-use of landfill for soilless systems, proximity to energy plants or computer farms etc.

4.2.4. Contribution of circular horticultural systems to sustainability

The greenhouse of the future must have nearly zero environmental impact. This goal can be achieved by developing a sustainable greenhouse system which:

- does not need any fossil energy and minimises the carbon footprint of equipment
- requires minimal amounts and does neither waste water nor causes emission of fertilisers and does fully recycle inputs such as water, nutrients and all growing media
- has minimal need for pesticides, yet with high productivity and resource use efficiency

Montero et al. (2011) presented an analysis and comparison of the environmental and economic profile of current agricultural practices for greenhouse crops, in cold and warm climates in Europe[3]. It was reported that the higher environmental impact of the greenhouses in the Netherlands is associated to the greenhouse climate control, structure, and auxiliary equipment. When a comparison between the high and low-tech greenhouses was made based on 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).

Life cycle assessment (LCA) studies, like the one noted above, determine the environmental impact of products, processes or services, throughout production, usage and disposal. LCA studies have emerged as a valuable decision-support tool for both policy makers and industry in assessing the cradle-to-grave impacts of a product or process and should cover not only local or European systems, but also the inputs and all their sustainability aspects even when the resources come from countries outside Europe (Global LCA). The question of labour resources should be taken into account as part of the social sustainability dimension. LCA should also cover the comparison between whether to use biodegradable material in components or long lasting ones.

The target in protected cultivation systems should always be to save resources and energy and to develop zero emission, closed circulation systems. The degree of circularity and sustainability depends on the quality of the inputs. This is very important for example for water input where sustainability of hydroponics and soil based production systems will depend on the quality and quantity of water. This problem is more important in Southern and Central Europe where the water quality, quantity or both is an increasingly critical production factor.

High quality economic data on circular horticulture are missing but would be essential to re-assure growers of the benefits that circularity can bring to their businesses. Practical examples include the price of resources such as water (input, output) in a circular system. Economic sustainability is by far the most critical driver in greenhouse production: without economic sustainability, no production will exist. In addition, society nowadays requires ecological and social sustainability. At the level of a company and product, such demands are addressed, for example, by carbon and water footprint calculators, allowing to reduce emissions. This is an important step towards viewing one's own business through a different kind of perspective and linking local production to the global picture.

For a greenhouse company, societal demands for increased environmental performance should preferably bring along higher cost-effectiveness and competitiveness. This is usually achieved through better technological

[3] See also the **Starting paper of FG-27** where the results for a 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 are presented.

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efficiency and effectiveness. Cost-reductions are always an excellent incentive for the uptake of new technologies in sectors with small economic margins. New business models are also needed. These business models – how the company creates value - should guide decisions on the choice of technological solutions and not the other way around. This may pose a challenge not only to growers, but also to technologically oriented advisers and facilitators who are supposed to support growers in their transition phase.

Social sustainability requires a discussion both at the level of the company and society. Clustered horticultural enterprises have a particular effect on communities nearby. They are able to offer working possibilities, boost local economic development and accumulate know-how, services and provide good ground for innovations and experiences.

The concept of the Circular Economy or Circular Horticulture and the potential to enhance sustainability are not commonly known. More and reliable knowledge is needed for both consumers and producers to change the mind-set from linear to circular horticultural systems. There is a need to promote success stories of circular horticulture systems so that they become common knowledge among the stakeholders. Demonstration of new, available technologies are also needed. For consumers, it is important to show the direct savings, sustainability gains etc., for example through a certificate like a "European Sustainability Label" which should be further developed.

4.3. Success and fail factors for circularity in protected cultivation systems

4.3.1. Availability of data and knowledge

Strategies to minimise waste and maximise the use efficiency of productive factors depend on a deep knowledge of characteristics and streams of the material used in the greenhouse production cycle, which in turn makes it possible to optimise material reuse and recycling potential. It is necessary to understand what the inputs are and where they come from, how effectively the production phase turns the inputs into products and how waste generated during the production phase and the phase of using the products is managed. Therefore, it is necessary to monitor, measure, combine measurements into metrics and interpret metrics into indicators that can represent the level of circularity of the system or process. The overall aim is to improve the performance of greenhouse systems by comparing the real situation with set targets and the study of the processes involved in the reach of the performance, so that more resource efficient and environmentally friendly management practices can be adopted. Positive economic and environmental effects on farm activities could be thereby achieved.

Significant knowledge gaps exist in relation to data gathering and monitoring at farm, region and even country levels. Very often, growers are not aware of the importance of metrics and data monitoring to characterise and quantify the use of or the amount of waste materials involved in the greenhouse production chain.

In 2016, the Horizon 2020 thematic network FERTINNOWA carried out a survey amongst 371 European growers regarding their fertigation practices and the applied technologies in both soil grown and soilless crops, as well as protected and open field cultivation. When these growers were asked about the yearly water consumption per m^2, only 83% of the growers responded. The remaining 17% did not answer to the question or were unable to provide any answer. Amongst the growers answering the question, a significant variation was found in the responses, even within the same region and the same crop. This raised the question again whether there is indeed a significant variation of irrigation practices under similar climate conditions and crops, or simply if there is a lack of monitoring and accounting. The survey showed that only few growers monitored the water inputs on their farm. Similar results are often obtained in surveys carried out to assess the use of fertilisers and pesticides. When it comes to effluents, on average 20% of the respondents replied that they would measure the nitrogen content of the effluents produced by their practices. But regional differences exist: while 45% of the respondents in the North Western part of Europe measured the nitrogen content of their emissions, only 11% of respondents in Mediterranean countries and 4% of in Central Eastern countries applied this practice. This trend seems to correlate with the existence of external control mechanism for emissions on farm.

Specific policy measures, public rural development strategies, advisory and expert services available should encourage effective and constant monitoring of greenhouse horticultural systems for example by grouping similar problems/subjects into clusters (clustering) with similar characteristics and exigencies. Greenhouse horticulture has ideal conditions (know-how, technical, economical) to reach high level of "circularity" if

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compared, for example, with other subsectors of intensive agriculture in open field that show less capacity to assess and control the flow of materials and waste. Therefore, data monitoring in EU greenhouse horticulture needs to be economically sustained through specific support programmes. Indeed, precise data monitoring and storage appears a worthwhile practice to improve circular economy in this agricultural subsector.

4.3.2. Quality and quantity of resources with special emphasis on water

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 needed by the plants (e.g. Na or Cl), then the 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 can lead to severe environmental problems and is an inefficient use of water and fertilisers.

Circularity of water might increase water availability at both farm and regional scale. One of the most well-known secondary water sources is drain and drainage water but condensation water from greenhouse ceilings could be a relevant water source as well to increase water availability at farm level. The use of disinfected urban wastewater might offer a valuable water source on a larger scale. However the reuse of secondary water sources may have specific bottlenecks such as the accumulation of sodium in closed hydroponic systems. Therefore technologies allowing selective sodium removal are on demand and more studies are needed on long term effects of growing media, soil or plants.

Transferring (also known as cascading) water to different processes closely located to each other, even without water treatment, can be considered as well for greenhouse horticulture. In fact, water quality reduction or low water quality does not have to be a problem for other industries.

Greenhouses usually are suitable for collecting rain water from the roof and this is very relevant in terms of water management if we consider the high quality of this resource. Thus, collection and storage of rain water may lead to an increase of circularity in protected cultivation systems. Rain water can be mixed with drainage water, something that is a common practice in all recirculation systems and allows for the operation of closed hydroponic systems in regions with low quality underground water. In this case rain water is mixed with the primary resource, thereby reducing salinity-derived problems. Moreover, stored water must remain clean. Ultrasonic treatment can help to keep the water free from algae and UV sterilisation systems can be used to avoid the spreading of pathogens coming from external sources. This is often done at the same time with closing the top of the storage when possible, which removes sunlight, reducing growth of algae.

However, some bottlenecks will have to be taken into account when thinking about rainwater storage. Growers who store water face problems related mainly to i) algae proliferation, ii) insufficient water storage capacity, iii) sediments, and iv) other issues e.g. losses through evaporation. Although rainwater can be considered a low cost water resource, its storage can be expensive. Indeed, a storage capacity must be big enough to allow accumulation of abundant volumes of rain water. Furthermore, storage requires additional investments to minimise evaporation losses and/or algae proliferation. This means significant construction costs and land occupation (if the water storage is at surface aboveground). Furthermore, rainfall patterns in typical Mediterranean type climates (with rainfall concentrated in a few days, but very low annual average) can be another problem. Solutions may involve collective rainwater storage. This may also involve cooperative work between regions and/or grower associations.

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4.3.3. Location and resources valorisation

Protected horticulture has an extensive range of stakeholders. Their presence in each region and active involvement and cooperation in the sector at different levels and with different roles and interests is necessary to implement circular principles in protected cultivation. The main direct and indirect stakeholders in protected cultivation include: greenhouse design and construction companies, horticultural farm input suppliers (seeds, fertilisers, biocides, growing media), ICT (Information and Communication Technologies) companies, greenhouse advisers, horticultural associations, agri-food processing and marketing chains, retailers, supermarkets, consumers, researchers, policy makers, governments and non-governmental organisations. Effective communication between the stakeholders and the clustering of stakeholders is not only required in the development and introduction of new technologies to increase circularity in protected cultivation systems, but also throughout the ongoing use and testing of these technologies.

Optimal solutions for circularity have not been developed for all regions in Europe or the Mediterranean. For example, the closed or semi-closed greenhouse concept that has been developed and is applied by 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 DSS for hydroponics: fertilisation needs for soilless crops have been mainly studied under Central and North EU conditions. They cannot be directly applied for Southern EU regions since the climate conditions vary between the different locations and water and nutrient needs may differ significantly (Schwarz et al., 2001; Medrano et al., 2005).

For the use of resources and outputs from a protected cultivation system, the streams have to be first quantified and assessed for their sustainable and profitable use. For example, the local use of biomass should be prioritised over long distance transport. Defining a sustainable action radius for biomass transport depends on the type of biomass to be transported. While straw-like materials have low bulk density, fresh crop residues or spent growing media are much heavier. Transport costs are region-specific and depend greatly on the local infrastructure and traffic, but overall they are higher for materials with higher moisture contents (green waste: 30-80 %) than for dry biomass waste. If a local use of biomass is not technically possible or does not make financial sense, centralised technological centres that collect various waste streams could provide a cost- and energy-efficient solution.

Some research initiatives to be suggested would be to carry out research on:

- Safe use of animal feed or fertilisers from converted rejected fruits and vegetables or plant biomass. Some restrictions on the use of fertilisers may arise in cases where it is not possible to move residues to fertilisation production plants.
- Changes in the use legislation related to the use of land. Urban farming can be difficult because the use of land in urban areas do not include agricultural production. This uncertainty might discourage potential investors or entrepreneurs. The same occurs in several countries when land is legally defined as "utilised agricultural land" and it is impossible to consolidate other activities such as energy, aquaponics, or microalgae production to link to the farming activities. In this case a denomination as "experimental activities" would make easier to set-up a cluster.

Finally concerning new business development, barriers such as the following may be found:

- New businesses carry a high risk of failure: The interdependency among the different value-chain actors as well as within the clusters require a solid management structure to avoid a "failure in cascade" due to fact that the products in one stage serve as raw material for the next stage.
- The risk is also high for entrepreneurs to scale-up laboratory or pilot processes into industrial scale in order to obtain bio-products from feedstock. This is an extensive and sometimes long-term investment with high uncertainty in the result.
- Immaturity of markets for new bio-products manufactured in clusters

Successful clusters have a solid organisation and are sufficient in size so as to be able to gain and manage funding from EU, national or regional programmes, from their own budgets and/or from investors. In this sense the participation of financial entities in the clusters is relevant to minimise risks for entrepreneurs. In an ideal

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case the cluster could take part in a public-private partnership like the Biobased Industries Consortium (BIC)[4] providing access to funding, knowledge, innovation and technology to the clusters members.

4.3.4. Level of technology and technology transfer

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

Soilless cultivation systems and especially closed or re-circulating hydroponic systems can significantly reduce fertiliser runoff but not eliminate it, and the spent nutrient solution has to be ultimately collected and treated at the end of the crop cycle, although the quantity is negligible compared with open (free drain) systems. Also, closed systems involve greater installation and running costs, they need a high degree of automation and technical skill and their economic viability is an issue under debate in southern Europe horticulture. As a consequence, the majority of the high-value horticultural production in Mediterranean countries use 'open' systems. Muñoz et al. (2012) presented an alternative way to reduce fertiliser 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 resulted in an important decrease in N leachate.

In addition, greenhouse units with a 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 equipment. Advanced climate and fertigation control systems and decision support systems are important tools to control the inputs and outputs of the greenhouse system and significantly affect the level 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 advisers consider the available DSSs too complex and lacking easy-to-use interfaces. Should relative controllers and DSSs be more widely available, then the application of closed soilless cultivation systems would possible. Nevertheless, commercial application of closed soilless cultivation systems is scarce, as their management is more difficult compared with open (free-drainage) cultivation systems. The 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.

In order to increase circularity in protected cultivation, a 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 introduction 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 the 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.

In general, specific triggers are identified that encourage technology uptake at the farm level, as listed below:

- The interest of the entrepreneur. This interest leads to the need for information, training, development instruments and experimental farms, demonstrations etc. that then lead to the development of a connection between industries and research, training and development organisations.
- The solutions should be affordable and reliable to justify and motivate their implementation in the economically challenged horticultural sector.

[4] http://biconsortium.eu

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- Availability of economic, environmental and technical studies that would support the implementation of the technology. Societal and environmental issues are the main ones that presuppose circularity; and the data on water and materials scarcity should be provided by technology providers to growers to raise awareness.
- The need for demonstration. Growers need reliable evidence of the suitability of certain technologies to adapt them to their situations. This requires particular efforts at the regional level, by the public and private sectors to demonstrated the techniques and practices that would increase circularity.
- The technical advisers of farms are key actors that need to translate the advantages of alternative solutions to the grower. Advisors should be trained in view of preparing targeted programmes for the use of specific technologies by growers.
- Growers are linked to markets through their products and services to consumers and society. Actions devoted to increasing the awareness of the wider public will increase market demand for sustainable products. Awareness among consumers on the benefits of circularity can contribute to their willingness to pay more for environmentally friendly products. Such promotion can be done directly by growers or by associations entrusted with the marketing the products at national and international levels. Sometimes the adoption of new practices could even open new markets, could be linked with the creation of new bio-based business value chains and make the adoption of circularity technologies more attractive for businesses
- Promote the impact? relevance of early adopters: the horticulture sector producers are located in specific areas, in which sometimes different companies are working in direct competition. Usually, there are "key" companies that act as technical references for the others, and the practices they use can be taken up as examples of good practices by the other companies. These companies could implement innovations and, in this way, could be considered as early-adopters, paving the way for larger user groups to adopt new technologies.
- ICT-based tools are necessary to boost knowledge and technology transfer for a circular horticulture. Examples include building a database containing relevant information from regional, national and European projects on circularity. This database could contain information on available knowledge, technology and processes either at laboratory, pilot, demonstration or industrial scales. The content of this database should be available to technical advisers so that they know about the advances in the fields of sustainability and efficiency of production steps, but also to other actors throughout the value chain, including logistics, packaging, and waste management. At these stages, the information on the database would be useful for entrepreneurs, who might start new businesses to give value to waste from current value chains. Such a database could be combined with a Geographic Information System containing a detailed analysis of current agricultural practices including the whole value chain in different locations, highlighting, for example the nature, frequency and amount of biomass generated. This information should be obtained from technical advisers and farmers, allowing a diagnosis of the level of sustainability and efficiency of the current value chains, benchmarking, as well as identifying gaps, concerning knowledge and technology. By matching both types of databases, a package of potential solutions for circularity and new business models, would be obtained at different stages: the primary production would identify solutions for farmers to be more efficient, waste would be reduced along the value chain and risks for entrepreneurs starting a new business would be minimised. ICT based initiatives to enhance knowledge and innovation are already on the way, initiated by scientific consortia and SMEs (such as the **https://www.smart-akis.com** network and **https://mysense.utad.pt/** IoT platform. Finally web platforms, networks, and specific events can boost the dissemination of circularity-related actions in order to promote the products generated with circular principles in the markets, boosting consumer demands.
- Public funding is necessary to boost new business models related to the circular economy, for example supporting entrepreneurs to scale-up knowledge and technology to commercial level, start-up creations and initial investments.
- Boosting public procurement of innovative technology to facilitate the access of farmers and other value chain actors to expensive infrastructures, for example, in the field of energy and ICT, which can be used all stakeholders.

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5. What can we do? Recommendations

5.1. Ideas for Operational Groups

The Focus Group identified several ideas for Operational Groups (OGs) related to circularity in protected horticulture, which are listed below:

1. Operational Group focusing on alternative and renewable growing media. Involve farmers in the process of production of alternative growing media to create trust among growers. For example trying to broaden the spectrum of input material for producing compost as alternative substrate. To link or cluster companies and logistics. To look at the risk of accumulation of contaminants and the potential reduction in new developed growing media blends during cultivation.
2. Operational Group focusing on the cooperation between farms. New business models can be created. For example in the processing of biomass, farmers can cooperate to interact with industries for the first processing of biomass. An intermediate entity with commercial skills can guide this process because often farmers do not have these skills themselves. Later on, the commercial skills can be developed by the farmers and farmers can be trained to interact better with other businesses and to develop cross-sector cooperation.
3. Operational Group focusing on rainwater storage. Optimisation of the use of secondary water like condensation water and water from cogeneration (the combined generation of electricity and other energy such as heat).
4. Operational Group focusing on mixed farming systems. To look at bio-digestion of manure and using biogas for heat production.
5. Operational Group focusing on urban farming. To look at the integration of buildings and greenhouses, e.g. by building greenhouses on the roofs of other buildings. CO_2 could be used from industrial processes or office buildings. In the case of roof top greenhouses, the outputs of a building (e.g. waste water, CO_2) could be used as input to the greenhouse and vice versa (e.g. heat from the greenhouse to the building).
6. Operational Group focusing on biomass for packaging. The OG will focus on the use of biomass waste produced from greenhouses as a source material for the production of packaging materials (e.g. carton containers). Some examples already exist.
7. Operational Group focusing on eco-designed greenhouses. Demonstration of the concept of eco-designed greenhouses (adapted or optimised passive design such as "Chinese" design) in order to transfer information to the growers.
8. Operational Group focusing on documenting experiences related to circularity in protected cultivation systems in line with- 'Seeing is believing'. These experiences must be identified and tested as well. This applies to any new strategy but particularly those requiring a change in the farmers' mind-set. Less successful examples should be also looked at as a means to learn by identifying the causes for "failure". Demonstration plots can be developed to show farmers in situ how the technology works, including its benefits and problems. Economics and break-even analysis customised for local conditions are desirable.
9. Operational Group to support data analysis and focus on the development and evaluation of indicators of performance of protected greenhouses in relation to circularity. A lot of data is available on different farms. The current trend of greenhouse crop management towards a tighter control of inputs and outputs (i.e. aimed at balancing resource inputs with crop demand) implies (i) characterising intra-greenhouse climate (ii) using crop-based information (crop indicators/descriptors) & (iii) enhanced analysis, interpretation and use of the collected data. A network can be created with farmers to collect this data and to share it with each other for peer to peer benchmarking. Some examples (e.g. for irrigation) already exist.
10. Operational Group focusing on the extraction of food, feed and high value molecules from biomass. This technology is still expensive. Investigations could be made to test the quality of the biomass and look at chemical and biological safety. The market potential can be assessed and an evaluation of the potential of these secondary products to become an important income source in the future, e.g. extraction of molecules and nutritional components for food printing. A solvent is usually used for the recovery of valuable components from agri-food by-products. Solvent extraction is not very selective and many other molecules are coextracted with the targeted ones which means that a separation processes is also needed to enrich

the extracts. Therefore, an OG on enhancing extraction efficiency through avoiding chemical solvents and using some kind of pre-treatment techniques or physical systems and how to preserve bioactivity of bioactive molecules would be very valuable for this sector.

In addition, the Focus Group proposed some more ideas for OGs related to specific topics of circularity in protected cultivation systems:

A) In relation to the **monitoring and metrics** of the systems.

- Operational Group focusing on the training of technicians and growers for improved education about monitoring and metrics in agriculture.
- Operational Group on the effective use of monitoring devices and data handling.

B) In relation to the **water quality and water availability** of the systems:

- Operational Group for increasing water use efficiency: diagnosis of the current situation, sharing good practices and techniques, implementation of good practices or techniques.
- Operational Group on the use of alternative water sources, available on local/regional levels. Implementation of demonstration sites in commercial farms.
- Operational Group on strategies and technologies to optimise water treatments and purification of horticultural wastewater (or leachates).

C) In relation to the **transfer of knowledge**:

- Operational Group focusing on training-the-trainers and in a second phase training the growers with regard to reuse of water and nutrients in greenhouses.
- Operational Group supporting circularity by linking farmers to other sectors such as urban waste water plants, plastic, textile, metallurgical industries, energy providers, waste treatment plants (heat), and create links of inputs and outputs between the different systems.

D) In relation to the **clustering** of systems-activities-knowledge related to circularity in protected cultivations:

- Operational Group dealing with the analysis of agrifood systems in terms of Life Cycle Assessment to allow to plan clusters facing environmental, social, geographical and economic challenges, identifying value chains to be integrated for achieving goals. The Operational Group would identify appropriate quantitative indicators of success. Experts on agrosystems analysis, agribusiness, researchers, farmers, environmentalists, biotechnologists and NGOs would work together in an Operational Group. The objective will be to value the environmental benefits associated to clusters by setting quantitative indicators such those used in LCA and footprints.
- Operational Group dealing with specific challenges of chemical and biological safety of materials flowing within the clusters, mainly those that are intended for food, pharma or cosmetic industry. Particular attention should be given to the safety and quality of products from open-air urban crops, recycled water destined to irrigation and safety of fertilisers from biomass. Experts on risk assessment, food safety, laboratory analysis, NGO, clusters managers and agribusiness would be involved in the Operational Group.

5.2. Research needs from practice

During the second meeting, the Focus Group identified the following specific research needs from practice.

1. Social/economical scientific approach to circularity: what is the consumers' perception of circularity? The general opinion is in favour but price and quality affects the actions. How far can consumers understand and give value to the growing conditions, LCA, nutritional properties, environmental aspects, limits set by nature against benefitting the low price and all year-round supply? What could the consumers do more to support circular production systems?

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2. "Chemical bottlenecks of circularity": Accumulation of nutrients. How to find new ways of removing accumulation like potassium, sodium, macro-organisms and metals. Which are the limits?
3. Breeding: in which respect can breeding contribute e.g. to the resistance of crops/cultivars to salinity, diseases? Can we develop varieties that will be more resistant to high salinity levels and thus help to increase the circularity of water and nutrients in greenhouses?
4. Nutrients: low cost technology solutions are needed for measuring nutrients, salinity etc. Can we develop sensors that will easily measure online the concentration of the different nutrients in the nutrient solution of hydroponic crops and thus be able to increase the reuse of drainage solution of hydroponic crops more efficiently?
5. Technical material, constructions and temperature control: what are the technical possibilities for saving, reusing , low-tech and high-tech solutions?

In addition, the Focus Group proposed some more ideas for research related to specific topics of circularity in protected cultivation systems:

A) In relation to **giving value to biomass** to increase circularity in protected cultivation systems:

- Production of dietary fibres or plant-derived proteins. An extrusion process could improve the digestibility of fibres (in terms of solubilisation of insoluble fibre) and also the content and bioavailability of bioactive components from horticultural biomass. Studies on the different process conditions (variables of the process) on extrusion cooking will result in a deeper knowledge for optimisation of the extraction process in relation to the type of biomass and potential commercial price.
- Alternative constituents for growing media. The replacement of peat, coir, mineral wool or other mineral products in growing media should also be accompanied by optimising the cultivation system in relation to new materials in growing media, e.g. by adapting the fertiliser application/fertigation needs. It should also take advantage of the nutrients of the alternative materials (e.g. compost as a source of nutrients, Vandecasteele et al., 2018) and cope with the possible issues regarding their practical management; in this regard, methods for monitoring the composition of the rhizosphere should be implemented in nurseries (Cáceres and Marfà, 2013). Looking in depth at N management in growing media, the increase in mineral nitrogen availability in such materials is important for plant nutrition.

B) In relation to the **monitoring and metrics** to increase circularity in protected cultivation systems, the collection of reliable data and the adoption of effective monitoring systems is currently limited by many factors at country and EU levels that could be addressed in specific research programmes focusing on the following topics:

- Standardised metrics and effective use of sensors for greenhouse horticulture and other intensive farming systems. Increase the perception of growers and managers for "data value".
- No autonomous data analysis software or procedure is available: standardised procedures of big data analysis have to be implemented to help farmers.

C) In relation to the **water quality and water availability** of the systems:

- Novel and cheap solutions for water storage to achieve smart storing of water. For example in large reservoirs (100x100m) floating covers are available, but expensive.

D) In relation to the **knowledge and technology transfer** to increase circularity in protected cultivation systems:

- Database and web app on new technologies, techniques, and practices for implementing circular horticulture. The focus should also be on examples of implemented technologies at farm level. All content should be translated into various EU languages to facilitate its dissemination.
- There is a need for new equipment and/or technologies fostering circularity such as biodegradable materials for ropes and clips that preserve their strength and quality during the growing season, technologies to recover nutrients and water, sensors, decision support tools, ….

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5.3. Other recommendations, including improving take up

During the second meeting, the Focus Group discussed the following specific recommendations:

- More holistic approach to water, pesticides, nutrients, micro-organisms. Could be also the case for other topics like biomass.
- We need to start from the bigger picture, i.e. not only taking into account the growers' point of view.
- How to stimulate the collective awareness about the need for circularity, including the farmer as an individual. How does the individual farmer perceive the need for more circularity? This is a matter of facilitating, stimulating and informing. How to achieve this? How to raise awareness?
- The key person for monitoring is the grower. How to facilitate data collection and management? Direct involvement of the different stakeholders (farmers, policy makers, researchers, technicians).
- Demonstration of the different strategies for improved water use efficiency among farmers and promote benchmarking.

In addition, the Focus Group proposed additional recommendations for research related to specific topics of the circularity in protected cultivation systems:

- Sharing of knowledge between researchers and farmers. Gain the interest of the farmers through one problem and discuss other ones at the same time (take advantage of EU projects eg. NEFERTITI, **https://nefertiti-h2020.eu**).
- Labelling: include expectation on circularity and sustainability in existing labels. How to link this with marketing? However the added value in circularity/sustainability labelled products only works for the early adopters, and if more and more producers adopt these new practices, the added value for doing things "better" disappears.
- Public perception on the use of recycled wastewater needs to be improved via research and educational programmes to successfully promote the use of treated wastewater recycling. This must be supported by research on factors influencing adoption of reuse technologies, such as the investment needs, operating costs and reliability.
- Environmental and social aspects are not sufficiently valorised. Usual indicators of success in clusters are the amount of inputs saved, as a measure of efficiency. The advantage of this indicator is that it is easy to translate into money for growers but the disadvantage is that it underestimates the total balance of benefits. Clusters need to value immaterial flows such as ecosystem services and social cohesion.

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7. Annexes

Annex 1: Members of the Focus Group

Name of the expert	Profession	Country
Bartzanas Thomas	Researcher	Greece
Beerling Ellen	Researcher	Netherlands
Berckmoes Els	Researcher	Belgium
Blanco Belén	Researcher	Spain
Caceres Rafaela	Researcher	Spain
Costa Joaquim Miguel	Researcher	Portugal
Di Lonardo Sara	Researcher	Italy
Egea Gonzalez Francisco	Researcher	Spain
Garcia Javier	Farmer	Spain
Grade Stefanie	Researcher	Germany
Grenet Alain	Civil servant	France
Lemmens Patrick	Adviser	Netherlands
Magán Juan José	Researcher	Spain
Massa Daniele	Researcher	Italy
Morel Chevillet Guillaume	Researcher	France
Nicola Silvana	Researcher	Italy
Pušenjak Miša	Adviser	Slovenia
Vandecasteele Bart	Researcher	Belgium
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Facilitation team		
Katsoulas Nikolaos	Coordinating expert	Greece
Morin Alexandre	Task manager	France
Desimpelaere Koen	Backup	Belgium

You can contact Focus Group members through the online EIP-AGRI Network.
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Annex 2: List of mini-papers

MP	Topic	Contributors
MP 1	**Circularity and/or Valorisation of Biomass: Crop Residues, By-products and Extraction of Molecules**	Stefanie Grade, (Coord.), Ellen Berling, Belén Blanco, Rafaela Caceres, Javier Garcia Checa, Sara Di Lonardo, Patrick Lemmens, Juan José Magán, Bart Vandecasteele, Robert Veberic
MP 2	**Clusters Raising Circular Horticulture Bioeconomy**	Francisco J. Egea Gonzalez, J. Miguel Costa, Guillaume Morel-Chevillet, Irene Vanninen, Patrick Eninge, Alain Grenet
MP 3	**Monitoring and metrics to boost circularity in horticulture**	Els Berckmoes, Joaquim Miguel Costa, Sara Di Lonardo, Juan José Magán, Daniele Massa, Irene Vänninen
MP 4	**Awareness raising and transfer of knowledge and technology in circular horticulture**	Ellen Beerling, Els Berckmoes, Rafaela Cáceres, Irene Väninnen, Javier Garcia, Fransisco Egea Gonzalez
MP 5	**Water use in greenhouse horticulture: efficiency and circularity**	J Miguel Costa, Els Berkmoes, Ellen Berling, Silvana Nicola, Juan Jose, Javier Garçia, Rafaela Caceres

Annex 3: Good practices and case studies

Several projects, thematic networks and research networks deal with resource use efficiency and increasing circularity in protected cultivation (Closys[5], Sirrimed[6], Euphoros[7], OrganicGH[8], EU Aquaponics Hub[9], Adapt2Change[10], OpIRIS[11], Flow-Aid[12], Fertinnowa[13], Euvrin[14] and others). 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 into the production process.

In the following, some good practice examples presented during the two meetings of the Focus Group are listed.

Juan José from Almeria, Spain

Treatment of fresh plant waste. The idea is producing **vermicompost** in a factory not located just in the middle of the greenhouse area to have enough space and using the final product in greenhouses for the crops. The problem when composting is how to manage the strings. They solved it by 'not cutting' the plant and using a machine where the string is progressively retained when moving the pile of waste to increase the oxygen level. Short irrigations are applied before planting to promote waste decomposition, moving salts (and nutrients) out of the wet bulk but trying to minimise leaching. No mineral fertilisers have to be applied for the first 4-4.5 months of the cropping. For that objective, the irrigation pipes are moved from the row of plants towards the corridor after the first 2-2.5 months, which promotes that the nutrients located in that zone move to the plants, supporting nutrition for 1 additional month. After that, as pepper crop is planted in double rows, a third irrigation pipe placed between the two rows is open and nutrients of this zone are also moved to the plants. One month later, is necessary to start the addition of chemical fertilisers by fertigation by basically using $CaNO_3$. The problem of applying this technique in Almería is the presence of the typical sand mulching, which makes difficult to soil application because to move the sand is very labour intensive. For that reason, we decided to eliminate sand mulching in this greenhouse by burying the sand into the soil. The commercial production for pepper was only 7% lower in comparison to a standard crop. The first year there were problems with salinity because of the use of bad-quality compost but this was solved the following year by using manure.

Morel Chevillet Guillaume, France

Aquaponics. 10 experimental station in France for horticulture. We work for the French minister and the French interbranch of plants' professionals. Mostly aquaponics are into the city. Intensive aquaculture need a lot of fish food with eutrophication and big problems for the environment. There is also intensive horticulture. When we mix both sectors we can solve both problems. The concept is explained see presentation. There are buffer tanks and you can cut both systems from each other. It is not 100% closed. You have to put water and nutrients in the system. We started in 2013 and go up to 2020. Main objective is to test the technical and economic part. A plot is in Lyon. There is a biofilter with bacteria. The plants are green leaves like lettuce and spinach but also tomatoes or strawberries are grown. One of the main purpose is also to look at optimal ratio between fish and plants. We need chelated iron. We look to efficiency for removal of the solids. Comparison of various plants between 2 experimental modalities. Main results on the website. Maximisation of water and water and nutrient recycling. Yields are satisfactory and water quality and fish survival is remarkable. Minimal size is more than 1000 m². Adapted to local marked. Products with medium to high value. The profitability is more for the fish production. Perspectives: sludge valorisation, objective zero outflow, sanitary aspects. Work on collaboration between fish producer and horticulture. In the Hague greenhouse at the roof with fish as well. Most important problems to solve. Economical aspect, competence of the farmer, what to do with the sludge. It is still waste. How much amount of sludge? It is known but the speaker did not have the answer on the spot.

Vandecasteele, Bart, Belgium

Horti-BlueC, Upcycling used growing media as biochar or compost. (https://www.interreg2seas.eu/en/Horti-blueC) Spent growing media can be a resource for Circular Horticulture.

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

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We want to replace peat and stone wool, being virgin raw materials that are not renewable, or coir, being non-sustainable, by biochar, compost, plant fibres and chitin. These materials may also allow for reducing the application dose of chemical crop protection and nutrients. The idea is to recycle used growing media as biochar or compost for new growing media blends.
There should be matchmaking between compost providers and growers (as potential compost users). For convincing growers for using compost in growing media blends, they want a standard compost quality and are hesitating to adapt their standard fertigation regime. It is difficult to produce and provide a compost with a standard quality. In some period woody bulking agents are in excess, and in other periods other materials (grass clippings) are in excess. If you can store woody material until periods with a lack of brown materials this misbalance can be solved. When the growers buy green compost, heat production in the heap after delivery should be avoided, since this points at a need for further compost maturation.

Vandecasteele, Bart, Belgium

Spent growing media as bulking agent in composting vegetable crop residues
For an optimal composting process a balance is needed between green and brown materials. N can be lost by ammonia emissions during composting when too high rates of green materials are used. In Flanders, there was a problem with leek residues, being available during winter without a good application strategy, while the vegetable growers did not have brown materials available. One option was to use spent growing media as brown material (bulking agent) for composting (Viaene et al., 2016). We replaced wood chips as conventional bulking agent by spent growing media from strawberries & tomatoes and chopped heat biomass from nature conservation. During the composting process moisture, CO_2 and temperature were monitored to optimise the composting process, to take care of bottlenecks during composting and for having an optimal process. As the peat-based growing medium came from soilless cultivation with fertigation and it contained a lot of nutrients, high loads of nutrients were introduced in the compost by using the spent growing media. This resulted in a compost too high in nutrients; especially for potassium and phosphorus very high concentrations can be present in spent growing media. Farmers do not realise that they remove a lot of nutrients from their greenhouses with the spent growing media. Another problem are the residues from chemical crop protection. There is potential for using less pesticides and fertigation during the cultivation, e.g., by compost application in the growing medium, and thus a higher potential for recycling the spent growing media. The compost is already a source of nutrients, thus less fertilizer input by fertigation is needed (Vandecasteele et al., 2018).

Beerling Ellen, The Netherlands

AquaReUse. (www.aquareuse.nl) An example of a **collective waste water treatment for reuse in greenhouse**. In The Netherlands there is not enough rainwater for the water needs of most crops. As a good supplementary water source ground water is used, after desalination. The remaining salty concentrate (brine) is brought back into the subsoil, which is not a sustainable solution. Another problem is the pollution of surface and groundwater due to leaching from greenhouses. Growers need to reduce the amount of discharge. In 2027 no emission of N and P will be allowed. One way is to reduce the amount of discharge from the greenhouse (zero-liquid-discharge). Another approach is a collective treatment of discharged water from several greenhouses. The plot is near The Hague, not very big. The objective is no use of groundwater and less pollution with discharged water. The system is explained see presentation. It concerns 85 ha and 11 greenhouses, with a total of 175.000 m^3 /yr combined domestic and greenhouse water. In short: the waste water is filtered first by a sand filter and a helophyte filter (for organic matter and N and P). The final step is reversed osmosis which results in 80% high quality water and 20% concentrated waste which is send to a communal waste water treatment plant. The high quality water can be used directly in the greenhouses, but when there is no need for additional water, it will be stored in the aquifer. All producers are involved, water board, municipality, developer and finally also the installer and supplier of the technology. In 2015 purification of the waste water started, in 2017 start of supplying irrigation water after guarantees that the water is of good quality. Not all growers use the water yet. It has to do with trust. They are not obliged to use it but obliged to supply all their waste water (there is no alternative). Complication is new legislation: all waste water needs to be purified for pesticides, also when delivered to sewage. This is not (yet) handled by AquaReUse. The solid waste from reversed osmosis contains pesticides, as does sludge from filters. So additional technology is needed to purify this. Next to connection costs they pay €0.67 per m^3, this price is competitive compared to if they have to desalinate ground water by themselves. The 20% of concentrate, can it be used for fertigation. A lot of P is precipitated and N is converted (50%) but quit some nutrients are still in it.

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Caceres Rafaela, Spain

A recirculating and **cleaning water** project (CLEANLEACH that right now is a technology that has been registered) www.cleanleach.eu. Outdoor container plant nurseries are, normally, open systems. They do not take care of water runoff, so there is a loss of nutrients and water. We can gather the leachate. We can use low energy systems to both, recirculate and to treat water. The reason of the project was the pollution of groundwater and the need of save water and fertilizers. CLEANLEACH combines two techniques, a horizontal sand filter (to gather water, so that water could be recirculated) and constructed wetlands (to treat the amount water that cannot longer be recirculated). It has been demonstrated that the sand filter (under the culture) will retain propagules of plant pathogens like *Fusarium* (this has been checked through massive inoculation trials). The constructed wetland will denitrify the nitrates of leachates in anaerobic conditions, but a carbon source should be added in order to enhance denitrifier activity. We applied first synthetic carbon sources; but the project execution allowed us to substitute this product by alternative by-products (contributing in this way to the circularity of the CLEANLEACH system). Other circularity improvements were the use of demolition gravel to substitute the normal gravel of the constructed wetlands; in addition, the macrophyte plants should be cut each year and this biomass can be composted and the compost can be used as a substrate which would substitute peat in the nursery.

Berckmoes Els, Belgium

Closed horticulture. The structure in Flanders is more scattered than in The Netherlands. Clustering of the greenhouses is less common. In general, the aim is to use less water and fertiliser. In the soilless growing systems this is done through closed system and recirculation. There can still happen small or big discharges, also wash water from filters. The water quality of the source water is a key factor for the degree of recirculation. In case the water contains higher salt concentrations, the need for discharge will occur more often. In soil grown greenhouse crops we see also discharges. Although the frequency of rinsing the soil has decreased significantly over the last years and has become a rare fact, still growers might face the need to rinse the soils. This is due to accumulation of the salts in the soil (either due to unequal irrigation patterns or due to the quality of the fertilisers). If you count the water and the nutrients that leach out this it is a lot. When you consider both the soil grown and soilless greenhouse crops we aim for an occasional to exceptional discharge. Therefore, we could provide a mobile system to clean the discharged water in order to meet the discharge criteria. Pre-treatment is very important. Removing pesticides is one thing, but removing the nutrients is another thing. Ion exchange is an option but still the economic feasibility of this technology in this concept has to be tested. Another point is the quality of the treated water. I t might require a mind switch of the growers to implement the water they first wanted to discharge. The recovered nutrients will have to be stored somewhere. For soilless crops the question is, can we have implement an extra nutrient stream in the system. How can it be implemented is a key question today. As the implementation of a mobile unit still poses lots of practical questions and requires some research and extra-long term demonstration, this will not be carried out in the FERTINNOWA thematic network but extra projects will be set up to investigate the specific possibilities for these mobile units.

LIFE **REVAWASTE** (http://www.revawaste.eu/): The general aim of the project is the sustainable management of a broad spectrum of wastes (non-recyclable fraction proceeding from waste treatment plants and industrial wastes, together with biomass, livestock and agro-food wastes) in a portable and integrated plant. This objective is reached by means of the technological development and practical application of the "mixed plant" concept which includes anaerobic digestion and pyrolysis technologies.

LIFE **LEACHLESS** (https://lifeleachless.eu/): The project proposes a portable treatment model that will be carried out "in-situ" using a cost-effective novel technology that combines solar evaporation/condensation plus forward osmosis. The prototype will be powered by renewable energies (solar energy, biomass and residual heat), which will minimise the carbon footprint of the process.

LIFE **ALGAECAN** (https://www.lifealgaecan.eu/): The project proposes a sustainable treatment model of highly loaded and salty effluents that combines in a portable pilot plant for cost-effective heterotrophic microalgae cultivation with spray drying of the collected microalgae to obtain a product of commercial interest as raw material for the production of biofertilisers, animal feed, bioplastic, etc.

Production of insects on waste biomass as fat and protein source. Arthropods can develop on different sources of organic matter, e.g. fruit and plant waste. In that way, plant biomass can be converted into animal

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flour with a higher content of proteins and fats, which can subsequently be used as an ingredient for or additive to feed for livestock, aquaculture or pets. Furthermore, high value products such as chitin, antibiotics or peptides with bio-stimulant activity can be extracted. These components can give an added value to the feed in comparison to presently-used protein sources (e.g. soya), thus reducing the demand for antibiotics in animal production. At the moment, this technology has not been commercially applied in Europe due to law restrictions but, in 2017, the European Union approved the use of arthropods obtained from plant biomass for food applications and there is presently a rekindled interest in it.

Production of insects from biomass waste: Bioflytech (**http://bioflytech.com**). A circular approach company (based in Alicante) for the management and recovery of organic residues and by-products through larval bio-digestion. Bioconversion or biotransformation of plant material is achieved by biological agents and processes, transforming them into high value products. The product derived from larval digestion includes a high-quality homogeneous and physically as well as chemically stable organic fertiliser with excellent agronomic properties for domestic use or to be marketed in agriculture. The process is compatible to organic production standards.

Biopesticide from fermented tomato plant waste (Friedman et al., 2004; Kalogeropoulus et al., 2012). It is known that strains belonging to the genus Bacillus have great capacities in controlling the development of phytopathogenic fungi due to the production of lipopeptides, proteases and kinases that degrade the fungal structure. Four endophytic Bacillus strains, isolated from roots, stems and leaves of tomato plants show growth inhibitory activity against Botrytis cinerea because of the production of heterogeneous mixture of antibiotics belonging to fengycin, surfactin, iturin and bacillomycin. This antifungal activity could be used for biopesticide production.

Pectin as edible food coating (Ciolacu, 2014; Giovanetti et al., 2012; Valdés et al., 2015). Pectic substances can be obtained from fruit and plant waste such as apple pomace or citrus mesocarp. Pectins are currently used for edible coatings of fresh and minimally processed fruits and vegetables. The functionality has been reported as "excellent barrier to oxygen, aroma preservation, barrier to oil and good mechanical properties, but they are not effective against moisture transfer through films due to their hydrophilic nature".

Vegetable waste for the production of natural aroma for the food sector (Edris et al., 2002; Soares et al., 2000). The utilisation of non-edible plant parts by fermentation for the production of volatile compounds of industrial interest has been proposed. Melon and garlic residues (aerial biomass) have been tested to obtain effective aroma.

Production of single cell protein (SCP) from food and agricultural waste by using Saccharomyces cerevisiae (Gervasi et al., 2018). In this study, the production of single-cell protein (SCP) by using food waste as a substrate was investigated. An increase of SCP from an initial content of 15.3 % to 39.8 % was achieved. The use of non-marketable fruits and vegetables for this purpose is conceivable.

Onion waste stream for the production of dietary fibres and bioactive compounds (quercetin, flavonols) (Benítez et al., 2011). Onion brown skin and top–bottom were shown to be potentially interesting as a source for dietary fibre as well as phenols and flavonoids with high antioxidant activity. The brown skin also showed a high concentration of quercetin aglycone whereas the outer scales were rich in flavonols. An industrial scale separation has yet to be realised.

Tomato fibres for production of packaging paper material. In the Netherlands, the company "The Greenery" has been using cardboard boxes made from tomato organic waste (leaves and stems) added to recycled paper. The company states on the web site: "Utilizing tomato fibres makes it possible to conserve energy and wood, while giving the tomato stems a second life as cardboard means they can be recycled again and again. Consequently, tomato fibres stay in the production chain longer, and reliance on virgin wood fibres is reduced. To illustrate: one hectare of tomato plants can be used to produce BioBased packaging for some 600,000 kg tomatoes." (Source: https://www.thegreenery.com/en/cases/cardboard-box-made-tomato-stems; 30.01.2018)

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Natural grass for the production of fibres for packaging material. Using a mixture of grass fibres and recycled paper, the Finnish company Huhtamaki was able to create a novel packaging material for the transport of eggs. (Source: http://www.huhtamaki.com/-/greenest-innovative-egg-packaging-made-with-grass-fibers; 30.01.2018). Packaging materials for fruits or vegetables could likewise be produced.

Biochar from residues in growing media. A good example is the use of biochar in growing media blends. Biochar has advantages like a better water quality in a circulation system because it absorbs sodium, especially at the start. Biochar can be mixed with other products to produce a substrate with a better bulk density. Biochar utilisation may offer interesting possibilities for the nursery sector or soilless cultivation not only in terms of increasing the effectiveness of irrigation (for its water retention) and by replacing peat, but also by enhancing the retention of nutrients and their availability for plant uptake, or increasing the disease resistance of crops (De Tender et al., 2016). Moreover, it can also permit the utilisation of low-quality irrigation water – thereby also reducing the leaching of nutrients such as K^+ and $N\text{-}NH_4^+$ (Di Lonardo et al. 2017). Finally, in soil poor in nutrients biochar alone could be effectively used to enhance soil fertility and plant growth and biomass yield. In combination with compost, it may optimise the composting process (Vandecasteele et al., 2016), and enhance and sustain soil biophysical and chemical characteristics and improve crop productivity over time (Trupiano et al. 2017).

Alternative constituents for growing media (green waste compost, plant fibres, mushroom compost). Growing media producers are facing restrictions in peat harvesting and the use of other non-renewable materials (rock wool). Whether alone or in mixtures, peat is the substrate constituent most commonly used in horticulture to grow seedlings and soilless plants (López-López et al., 2016), particularly in Europe (Bonaguaro et al., 2017).The European growing media market size is estimated at about 37 million m^3, with peat representing 80 % of this amount (Aleandri et al., 2015). Many substrate producers have been successfully using wood fibres and compost in professional growing media, but nitrogen immobilisation is still an issue. There is a need for fast and cheap techniques to screen biomass types for their suitability to replace peat or rock wool. Many studies have been performed using different feedstock for its use in growing media mixtures after composting (Barrett et al., 2016). Common challenges in using compost in soilless media are due to: immaturity of the compost, poor water holding capacity, and unbalanced salinity and pH (Rogers, 2017; Aleandri et al., 2015; Cáceres et al., 2015). Recently, natural acidification through nitrification using green waste with solid fraction of cattle manure has been a suitable method for obtaining appropriate peat substitutes since pH of compost are normally high (Cáceres et al., 2006; 2016; 2018). The use of processed plant fibres (e.g. miscanthus straw, reed straw or flax shives) in growing media allows to reduce the demand for peat and to close resource loops, but the risk for nitrogen immobilisation should be assessed. Successful pre-colonisation of this straw with biological control fungi allows optimising crop cultivation, requiring fewer pesticide applications, which will benefit the environment and human health (Debode et al., 2018, https://youtu.be/_qfFLVWS3Mo). In mushroom production, the reuse of spent mushroom compost is a good practice, but a complete recirculation is not yet achieved due to degradation during production and recycling. The accumulation of production residues (root system/mycelium, nutrients or pesticides) also limits the reusability of growing media. The acceptance of reuse by the farmers and growers for fear of contamination and yield losses may also be an obstacle. Depending on the cultivation method, reclamation/reuse of the growing media is not possible – the material is either sold with the product (e.g. potted plant) or transplanted into open field production. For other cultivation methods, the recycling potential of spent growing media should be increased by a feedback loop to the cultivation practices (e.g. for reducing the accumulation of nutrients and chemical crop protection products).

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Annex 4. Statistics on protected cultivation in the EU

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 A1.1. Areas (in ha) under cover cultivated 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 A1.2. Number of holdings/farms under cover with vegetables, flowers and permanent crops (source: Eurostat 2017)

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CROPS ▸ GEO ▾	Lettuces - under glas	Tomatoes - under gla	Cucumbers - under g	Peppers (capsicum) -	Strawberries - under
European Union (28 c	12.04	41.56	14.76	:	19.97
Belgium	1.01	0.51	0.04	0.09	0.56
Bulgaria	0.10	0.59	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 A1.3. 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 c	:	:	:	:	:
Belgium	43.39	253.05	16.85	25.48	:(z)
Bulgaria	1.66	50.11	41.58	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	2.82	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)	6.79
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	56.97	14.36	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	36.80	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	:	:	:	:	:

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

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AGRICULTURE & INNOVATION

The European Innovation Partnership 'Agricultural Productivity and Sustainability' (EIP-AGRI) is one of five EIPs launched by the European Commission in a bid to promote rapid modernisation by stepping up innovation efforts.

The **EIP-AGRI** aims to catalyse the innovation process in the **agricultural and forestry sectors** by bringing **research and practice closer together** – in research and innovation projects as well as *through* the EIP-AGRI network.

EIPs aim to streamline, simplify and better coordinate existing instruments and initiatives and complement them with actions where necessary. Two specific funding sources are particularly important for the EIP-AGRI:

- ✓ the EU Research and Innovation framework, Horizon 2020,
- ✓ the EU Rural Development Policy.

An EIP AGRI Focus Group* is one of several different building blocks of the EIP-AGRI network, which is funded under the EU Rural Development policy. Working on a narrowly defined issue, Focus Groups temporarily bring together around 20 experts (such as farmers, advisers, researchers, up- and downstream businesses and NGOs) to map and develop solutions within their field.

The concrete objectives of a Focus Group are:

- ✓ to take stock of the state of art of practice and research in its field, listing problems and opportunities;
- ✓ to identify needs from practice and propose directions for further research;
- ✓ to propose priorities for innovative actions by suggesting potential projects for Operational Groups working under Rural Development or other project formats to test solutions and opportunities, including ways to disseminate the practical knowledge gathered.

Results are normally published in a report within 12-18 months of the launch of a given Focus Group.

Experts are selected based on an open call for interest. Each expert is appointed based on his or her personal knowledge and experience in the particular field and therefore does not represent an organisation or a Member State.

*More details on EIP-AGRI Focus Group aims and process are given in its charter on: http://ec.europa.eu/agriculture/eip/focus-groups/charter_en.pdf

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