Analysis of solid waste in urban agriculture in the frame of the circular economy: Case study of tomato crop in integrated rooftop greenhouse

Ana Manríquez-Altamirano[a], *Jorge Sierra-Pérez[a,b], Pere Muñoz[a,c], Xavier Gabarrell[a,c]

[a] Sostenipra (ICTA-IRTA-Inèdit; 2017SGR 1683), Institute of Environmental Science and Technology (ICTA; Unit of excellence «María de Maeztu» (MDM-2015-0552)), Autonomous University of Barcelona (UAB), Building ICTA-ICP, Street of the Columns, 08193 Bellaterra, Barcelona, Spain.
[b] Department of Design and Manufacturing Engineering, EINA, University of Zaragoza, María de Luna 3, 50018 Zaragoza, Spain.
[c] Department of Chemical, Biological and Environmental Engineering, Reference Network in Biotechnology (XRB), School of Engineering (ETSE), Autonomous University of Barcelona (UAB), Campus of the UAB, Bellaterra (Cerdanyola del Vallès), 08193 Barcelona, Catalonia, Spain.

Corresponding author: jsierra@unizar.es (Jorge Sierra-Pérez)

Abstract

Within urban agriculture (AU), integrated rooftop greenhouses (i-RTG) offer multiple benefits. Currently it is intended to improve environmental benefits by taking advantage of its flows. However, the use of solid waste (SW) flow has not yet been thoroughly investigated. The objective of this research is to identify what type of i-RTG SW has the potential to be used from a circular economy (CE) perspective and propose a type of management for its material valorization.

The results of the case study show that, with respect to the possible management for each type of SW generated, the biomass has the greatest potential to be used locally, particularly the tomato stems. They were chosen to be used as a substrate for lettuce crops in i-RTG. The results of the two experimental lettuce crops show that tomato stems have a better yield as a substrate after a prewash treatment, since at first the values of electrical conductivity (EC) are very high with respect to the control of the substrate, which is expanded perlite.

In conclusion, we can say that it is possible to increase the environmental benefits of i-RTG by taking advantage of its biomass locally. This would also help to foresee a possible future problem regarding the inappropriate management of the residual biomass of i-RTG within cities. This research has as a general objective to help change the paradigm about the perception of the SW of the AU to give them from the beginning an adequate management for their local use as by-products.

Keywords

Integrated rooftop greenhouse, agro-urban solid waste, circular economy, tomato stems, organic waste substrate.

1. Introduction

1.1. Rooftop greenhouse: Efficient urban agriculture

According to the United Nations Food and Agriculture Organization (FAO), between 2009 and 2050, population growth will increase the current population by one-third, mostly in developing countries. As a result, one in 10 people in the world (9.3%) suffered from severe food insecurity, equivalent to approximately 689 million people (according to data collected in 2014, 2015 and 2016 from 150 countries) (FAO et al., 2017). Currently 55% of the world population lives in urban areas and it is expected to increase between 68-70% for 2050 (United Nations, 2018). Urban agriculture (UA) could help meet this food demand by then. It is constantly growing in increasingly populated places like Paris, London and the Netherlands since the 1990s, and countries such as the United States, Canada, Germany and Spain are currently committed to the development of urban agriculture (Pons et al., 2015). Many of the UA projects are developed in open roof farms, indoor agriculture and rooftop greenhouses that refer to the use of greenhouse methods with soilless cultivation systems in most cases, such as hydroponic techniques adapted for use on top of buildings. This reduces the structural load on the building and increases resource efficiency so there is currently a growing number of rooftop greenhouses within cities (Sanyé-Mengual et al., 2015; Specht et al., 2014). In addition to addressing food demand and provide fresh fruits, vegetables and herbs, UA contributes to reducing the environmental impact of cities by providing food without the need for transportation from distant farms. Similar reductions in impact come from reduced packaging for transport to cities (Puri & Caplow, 2009).

1.2. Circular economy: The potential improvement of waste management in RTG

The circular economy (CE) emerged as an initiative in the face of the global problem of resources depletion and climate change to try to change the way the entire economic system works from linear to circular flows (Korhonen et al., 2018). By rethinking the way we produce, work, buy and dispose, making special emphasis on find value to the waste taking advantage of them. To this end, in December 2015, the Action Plan for the Circular Economy was approved for the European Union (EU) (EU, 2015), which will contribute to closing the life cycles of the products by increasing the rate of reuse and recycling of materials. In CE, the value of products, materials and resources are kept as long as possible, minimizing the material raw extraction, generation of waste and the emission of greenhouse gases related to the new production of products or those related to waste management, making resources and energy more efficient (Camarsa et al., 2017; Korhonen et al., 2018). Within the perspective of the CE, the waste of one process becomes the raw material of another. Currently the states of the EU are obliged to implement from a legal framework, the Action Plan as "waste hierarchy" that includes a descending order of priority for the management of waste from a mainly environmental perspective. The first is prevention, followed by preparation for reuse, recycling and recovery and finally elimination (European Parliament, 2008).

Under the CE approach, the environmental benefit of the AU, could be improved by closing the water, gas and waste cycles. This would represent more sustainable production (Piorr et al., 2018). Integrating the different flows of the building to the rooftop greenhouse (RTG) to make resources more efficient is a way to improve environmental benefits (Sanyé-Mengual et al., 2014). A study by Sanjuan-Delmás et al. (2018) regarding this, quantified the environmental savings of an integrated rooftop greenhouse (i-RTG) in Barcelona with a tomato crop and compared it with a conventional greenhouse 500 km away in Almeria (Spain's main producer of tomatoes). Their results show that i-RTG can operate with less than half of the environmental impact compared to conventional greenhouses (0.58 kg of CO_2 equivalent per kg of tomato vs. 1.7 kg of CO_2 equivalent, respectively). However, the flow of solid waste (SW) to be used has not been considered yet. This would further improve the performance of i-RTG within the frame of the CE.

1.3. Agriculture solid waste and its management

SW is considered to be materials that are not main products within a linear economic system that are generated during different stages of production, consumption and use and there is no additional use for them, so they are discarded. So the outputs of the agricultural production system without counting the main production, could be considered waste unless this material is recycled or reused at the generation site from the perspective of CE. Agricultural SW is traditionally classified, according to its nature, organic and inorganic. Highlighting the organic for its high volume of production and the strong environmental impact they cause without proper management. Agricultural organic SW is characterized by its seasonality. The biodegradability of these materials depends on the relative content in easily degradable biomolecules (soluble and low molecular weight sugars, hemicellulose and cellulose) and slow degradation components (waxes and lignins)(Martínez Rey, 2014).

On the other hand about inorganic SW, it is necessary to differentiate agro-urban SW from agricultural SW from conventional crops outside the cities as they differ greatly by typology, from the infrastructure, to the tools for the operation process and the equipment used for different techniques such as hydroponics that require another type of substrate. The systems without soil, in addition, require additional material such as benches, collection tubes, substrate bags, film that covers the floor, etc. (Antón & Muñoz, 2013) generating a large amount of SW. The volume that is generated according to the type of waste is different, for example, in hydroponics, the amount of raffia yarn used is up to 4 times higher than in the conventional system, partly because it is frequent the use of the pick-up system. The amount of plastic bags used is double that in the conventional system (Dupri, 2006). On the other hand, the organic SW is less than that generated in conventional crops since the cultivation area is usually smaller. However, the management within the cities cannot be the same as in the crops in the fields where it could be reintegrated into the land as a compost or amendment (Sanyé-Mengual et al., 2016). Within the different methods of SW management, and in addition to the traditional ones, such as landfill and reuse (which is considered the best option whenever possible), we find recycling, which consists of taking advantage of waste materials through any recovery operation and converting them into by-products (European Parliament, 2008). Material valorization proposes the recovery of waste and its use as a raw material to develop new products and thus help conserve natural resources. Energy valorization, seeks to reduce the volume of and recover the energy from gases, liquids and solids that are generated by the thermal processing of wastes, these processes either require oxygen (e.g., boilers or incinerators) or do not (e.g., pyrolysis, thermolysis and biomethanization) (Dupuis, 2012; Energía, 2013; Yepes et al., 2008). Material valorization, which can be either mechanical recycling though processes such as grinding or extruding material, has priority over energy valorization according to the EU waste hierarchy (European Parliament, 2008). Chemical recycling that breaks down the elements of a material in order to obtain new materials, can be considered complementary to mechanical recycling, since both processes together can result in large amounts of clean, separate and homogeneous SW with a guaranteed quality of the final product (CEDEX, 2013).

Antón and Muñoz (2013) present a comparative research on the waste generated in a conventional greenhouses, their management and the environmental impacts as well the energy demand related to their life cycle. They also make a description of the type of waste generated in greenhouses to recycling by dividing it into: plastics, metals, substrate and biomass for compost. Based on this division, we will identify the type of management that could be done to take advantage of the SW from the i-RTG, either by reusing it, recycling it to make a by-product in order fix the carbon or, in the last case, its energy valorization.

1.4. Waste valorization

1.4.1. Plastic

There are different ways to take advantage of agro-urban waste plastics. Thermoplastics as low density polyethylene (LDPE), the material from which the substrate bags are made, have a high calorific value and for this reason it could be considered the energy recovery (CEDEX, 2013). On the other hand, the material use through recycling is a simple process since by applying heat, they can be melted and molded several times without significantly altering their properties (approximately 6 times) (CEDEX, 2013). Within this type of recycling, LDPE, is the polymeric material with the highest consumption due to its low cost and ease of processing (Amigó et al., 2008; Sevigné-Itoiz et al., 2015). This material can be used to manufacture films, irrigation hoses, asphalt fabrics, containers, bags, baskets, sacks, buckets, pots, etc. (Urrestarazu et al., 2005). Another form of material valorization using the same mechanical processes, is the development of composite materials or composites. It involves mixing the plastic with other products to improve the physical characteristics of the by-products (Amigó et al., 2008). Currently, it has been studied and worked largely on the incorporation of natural fibers as a reinforcement of polymers, which improves properties such as the strength and rigidity of the polymer (Satyanarayana et al., 2009).

1.4.2. Substrate

Expanded perlite has a porous cellular microstructure that makes it very light for a mineral material, and therefore very valuable to industries such as construction and agriculture (Kotwica et al., 2017). As a substrate, it is widely used because, in addition to being light, it is inert and is easy to use in RTG crops such as tomatoes. Perlite can also be reused several times, thereby reducing costs (Acuña et al., 2013; Hanna, 2005), although it must be processed between crops, because it may become contaminated with pests or other hazards. A study by H. Hanna (2005) determined whether reusing perlite (after cleaning and disinfecting) for growing tomatoes is more cost effective than replacing it, without having a negative impact on yield. In any case, it should be considered that there may be loss of material during the use face due to handling and also during the washing process if used. The treatment, hot water disinfection, saved 56% of the cost and can be applied for several years without significantly changing the physical condition of the perlite. An important finding regarding the use of perlite, particularly for soilless crops in RTG, is the retention rate of nutrients: approximately 6% of incoming nutrients are retained (7% for phosphorus and 5% for calcium) (Sanjuan Delmás, 2017), which is good to consider when reusing it as substrate. As a waste by-product, the properties of expanded ground perlite have been studied for use as a substitute for cement or as an additive with pozzolanic activity (Kotwica et al., 2017). It can also be incorporated as an amendment to clay soils when previously disinfected. It has been shown that this material does not affect crop production (Acuña et al., 2013; Urrestarazu et al., 2005) On the other hand, considering that it is a relatively new material, there are several studies for alternative uses of perlite, since it has a low thermal conductivity compared to other mineral materials. For example, perlite may be used to create panels and bricks, since it has thermal insulation properties and an acoustic absorption coefficient that are similar to other granular materials, although with a greater density (Schiavoni et al., 2016). Mixing perlite with other materials to create composites has resulted in better properties for the creation of panels (Li et al., 2016) in which case only new perlite is used. Expanded perlite particles (unused) have also been studied for processing by countergravity infiltration with aluminum to form synthetic foam (Taherishargh et al., 2014). Furthermore, perlite has also been tested with additives for the production of concrete with good results (Señas et al., 2004).

1.4.3. Biomass

Currently, the material valorization of residual biomass has been extended due to the interest in creating new ecological materials with it. To that end, several researchers around the world are conducting detailed analyzes studying organic waste materials (Demertzi et al., 2017; Sierra-Pérez et al., 2018; Sierra-Pérez et al., 2016). These materials are generally classified as "unconventional" materials since they are still in a pre-commercial stage (Schiavoni et al., 2016). The matrices of biodegradable polymers reinforced with natural fiber (biocomposites) are evidence of this trend that has shown to have good results. The study done by Jústiz-Smith (2008) characterizes sugarcane bagasse, banana tree trunk and coir to evaluate their potential as a reinforcing material. For its part, Amigó (2008) conducts a study on cotton and linen textile waste fibers, as well as sisal, hemp, fique and kenaf fibers from rope manufacturing wastes for the same purpose. In addition to the characterization of this type of lignocellulosic fibers as reinforcement for polymeric matrices. There are also very complete studies in terms of market, processing methods, matrix reinforcement systems, morphology, properties and product development such as the overview study that Satyanarayan (2009) performs on the bagasse of sugarcane, peel, jute, flax, pineapple, sisal and cotton for reinforcement in mixtures with different types of polymeric matrices. The development of biodegradable pots using hemp fibers combined with seeds and husks of tomatoes and alginate as a binder has also been experienced. The same materials that make films or sheets were demonstrated to have good mechanical properties that could be used to improve existing products, making them eco-friendly (Schettini et al., 2013). On this subject, there is an investigation (Nisticò et al., 2017) about the use of postharvest tomato plant parts as fillers to manufacture films composed of synthetic polymers from fossil sources, in which the mechanical properties of the tomato waste are defined. The results showed that the film can be competitive in cost, performance and sustainability. Natural fibers for reinforcement are also used to make polyurethane foams, as shown by the research from the National University of Costa Rica, where they use waste molasses and cane bagasse fiber as reinforcement material with positives results (Vega-Baudrit et al., 2011). On the other hand, most of the residual biomass generated within the cities that is managed at the municipal level is composted and the rest goes to the landfill. About the residual or waste biomass generated in Spain, the 60% of biodegradable municipal waste from parks and gardens is composted while 36% ends up in landfills and 4% is incinerated (MITECO & INE, 2016). The final destination of the waste biomass depends on many factors such as the type of crop, the volume generated, and the proximity of composting or biomass recovery plants, the latter determine whether it can be used in the place where it was generated and the possible transport costs, which would, in turn, determine the economic viability of its reuse (Energía, 2013). Burning or incinerating urban waste biomass is not tenable because these processes are currently highly controlled or even prohibited, they can cause damage to the soil and the environment due to smoke emissions, and there is the risk of contamination with nonorganic waste (Dupuis, 2012; Mendoza, 2010).

Composting or vermicomposting biomass is also a traditional option for management (Anton et al., 2005; Burés et al., 2014; Dupuis, 2012; Hubbe et al., 2010; Muñoz et al., 2003; Ros, 2012) since it produces stabilized organic matter, free of pathogens, which, when applied to the soil is beneficial in that it improves soil structure and water retention. Composted biomass could be used as a substrate component for ornamental plants, gardening (Quintero et al., 2011) landscaping, and forest nurseries as explained in a characterization study by Mendoza Hernández (2010). In this way it can also be used as an amendment, as a conditioner acting on many of the properties of the soil, as a fertilizer providing nutrients, or even as a substrate for soilless crop (Urrestarazu et al., 2005). There is a study (Martínez-Blanco et al., 2010) about the comparison between the environmental impact generated by composting management at the municipal (industrial) level and local management (home composting). In general, the results show that home composting with an energy consumption of 351 MJ eq and the emission of 220 kg CO_2 eq per ton of organic fraction of municipal solid waste (OFMSW) has greater benefits than industrial composting with consumption of energy of 1908 MJ eq and 153 kg CO_2 eq per ton of OFMSW, mainly due to the reduction of environmental impact (1.5 times less) related to the collection and transport of organic SW to the industrial composting plant and the transfer of compost already made to the area where it will be used. In addition, the energy consumption related to the industrial compost process is between 5 and 6 times higher than home composting. However, the emission of gases such as nitrous oxide, methane and ammonia that are released during the process of making homemade compost is greater than in the industrial process (5-8 times greater) where they use forced aeration and biofiltration of the exhaust gases. Particularly in the case of i-RTG, the results of the study focused on life cycle assessment (LCA) of Sanjuan-Delmás (2018), show that composting biomass is a critical point due to the release of gases during the process, which generates 25% avg. of the impact on terrestrial acidification and 12% avg. of the impact on climate change.

2. Case study

2.1. Tomato crop in i-RTG: FertileCity project

In recent years, urban agriculture projects have been developed within and on buildings in order to save natural and energy resources (Thomaier et al., 2015). FertileCity project is an example of RTG that is developed on the upper floor of the ICTA-ICP building in Barcelona, in the Urban Agriculture Laboratory (LAU1). Which are based on a horticultural production system connected to the building in terms of water, energy and CO_2, for research purposes on food production from a sustainable approach as an i-RTG (Sanjuan-Delmás, 2018). The type of tomato grown in the LAU1 is heart of ox ("cor de bou") (Solanum lycopersicum) variety Arawak for spring and Tomawak for winter (Sanjuan-Delmás et al., 2018) using expanded perlite as a substrate. During the crop, regular pruning is carried out as part of the maintenance of the tomato plants. All the residual biomass in the LAU1 is weighed by rows to keep track of the amount of organic solid waste that is produced in the crop. The destination of this type of waste would commonly be its deposit in the organic waste containers that are managed at the municipal level as part of the selective collection of organic urban SW (industrial composting).

3. Justification and aim of the study

Several studies have been carried out around the cultivation of tomatoes of the FertileCity Project using mainly the methodology of LCA with theoretical (Pons et al., 2015) and experimental data (Llorach-Massana et al., 2017; Llorach-Massana et al., 2016; Piezer et al., 2019; Sanjuan-Delmás et al., 2018; Sanjuan-Delmás et al., 2018), in order to make a more sustainable system, improving its environmental performance and the efficiency of its resources. There are only two studies focused on the use of organic solid waste from i-RTG tomato plants (mixture of 50% stems with 50% branches and leaves) in order to fix CO_2 as by-products, as biochar (Llorach-Massana et al., 2017) and as thermal insulation material for building (Llorach Massana, 2017) The results of those studies show that the insulation material has 8% lower net emissions than biochar and higher capacity to fix carbon for long periods than the biochar because part of the carbon in the biochar (50%) is not considered stable. Even though for the insulation material the tomato plants represent just the 30% of the total mass because it must mix with other raw materials as sand and lime and the thermal performance with respect to the density is not efficient (a high density with this material is required). On the other hand, the process plants to make the by-products are consider 25 km far away from the i-RTG (in the industrial area located in northern or southern Barcelona) (Llorach Massana, 2017). However, from the circular economy approach it is important to consider the use *in situ*, which would eliminate the impacts related to transportation to any energy or treatment plant for example. The objective of this study is to identify what type of SW from the tomato crop of the FertileCity i-RTG project has the potential to be used locally from a CE perspective considering the flow of its generation and the type of management needed for each case. Based on the above, to make a proposal for the use of the SW selected as an approximation for future research in this area and thereby help fill the gap with respect to the improvement of the environmental performance of the i-RTG life cycle from the flow of SW.

4. Materials and Methods

4.1. Classification and quantification of i-RTG SW flow

The SW flow from the Urban Agriculture Laboratory (LAU1) of the FertileCity project with a total crop area of 84.34 m^2, where 171 tomato plants grown in a soilless system, described in Sanjuan-Delmás et al. (2018), is used for this study. Expanded perlite is used as a substrate in 57 low density polyethylene (LDPE) plastic sacks OTAVI S&B brand (three tomato plants in each sack). Three tomato crops are considered carried out between February 2015 and July 2016: S1 (spring-summer) from 10/02/2015 to 23/07/2015 (164 days); W (fall-winter) from 15/09/2015 to 04/03/2016 (169 days); S2 (spring-summer) from 08/03/2016 to 20/07/2016 (133 days) (detailed information can be reviewed in Supplementary data). August 2015 is excluded due to inactivity in the building coupled with the high temperatures that make cultivation difficult. In addition, we incorporated the S3 extended tomato season (189 days), from 12/01/2017 to 18/07/17, for a measure of biomass volume. The SW flow of the LAU1 for crops S1, W and S2, was calculated based on the compilation of data from the inventory of materials, along with data of crop monitoring, production (commercial and non-commercial tomatoes), pruning (leaves and branches) and quantification of biomass at the end of the crop (2015 and 2017) which is composed of the main stems of the plants along with their branches and leaves. For research purposes, at the end of the crop the stems are cut to 20 cm from the base of the substrate bag. Subsequently, all branches along with the leaves are separated from the main stems and also weighed and measured separately. All this biomass is placed on the ground for natural drying for 3 months in a covered area in the same building with similar conditions to those of LAU1 to be analyzed and perform experiments (Fig.1). Once the stems are dried, they are measured and weighed again to identify the percentage of moisture lost.

(a) (b)

Fig. 1. Tomato stems without branches or leaves, extended in the LAU2 for drying. (a) freshly cut wet stems; (b) dried stems 3 months after cutting.

It is also considered as part of the inventory the inputs of the i-RTG tasks, leaving aside the greenhouse infrastructure (building-LAU1) and the energy, gases and water flow (that is recirculated) along with the nutrients, fertilizers and pesticides that are applied to the crop. Also leaving aside the inedible tomatoes for being a very irregular flow, not constant with respect to time and its volume of generation. The amount of each materials used in the three crops was averaged and according to the life time of each material, the volume generated per avg year, per kilogram of tomato (production), per crop area (m^2) and per avg number of plants in the crop, was calculated (see Table 1). The production of 1452.9 kg/year avg. of edible tomatoes was considered just as ratio reference.

4.2. Identification of SW with potential to be used locally and the choice of its management

Based on the results on the classification and quantification (Table 1) of the SWs of the i-RTG and based on the literature regarding the management for each type, the SW with the greatest potential to be used locally from a circular economy perspective was identified and was performed a proposal for its use.

Table 1. Main iRTG SW and its generation per average year.

			Total per 1 year avg		
RTG solid waste	Materials	Unit	Per crop	Per kg of production (tomatoes)	Per m^2 (crop area)
Expanded wet perlite	Mineral	kg	207.06	0.14	2.45
Pruning waste	Organic	kg	226.09	0.15	2.68
Branches and leaves	Organic	kg	204.05	0.14	2.42
Main stems	Organic	kg	129.05	0.09	1.53

4.3. Proposal for the use of SW selected into the i-RTG

Two experimental lettuce crops grown in a soilless system were made using tomato stems as a substrate. This with the objective of proving in a practical way a potential application for its local use and making an approximation from the agronomic point of view. The experiment was carried out in part of the Urban Agriculture Laboratory 2 (LAU2) of the ICTA-ICP Barcelona building with temperatures between 20 °C - 33 °C. The description of the experimental design for both crops and the treatments that were applied can be reviewed in Supplementary data. To make the substrate, approximately 13.5 kg of dried tomato stems of the 2017 crop dried at room temperature (under similar conditions to LAU1 described in section 4.1) were used. They were shredded with a Tecnoinsaen, sl. machine Model: ECO 5.5 Power: 4Kw, 1 Phase Type: 90L/2, Hz 50, Kw 2.2. The stems were passed only once through the shredded machine and fiber lengths between 0.5 and 10 cm were obtained.

Half of shredded stems for crop were disinfected in an autoclave for 40’ at 121 °C. Autoclaved disinfected tomato stems were identified as TT and uninfected (untreated) as UT. The plastic bags for perlite substrate were emptied and reused to make bags with an average capacity of 17L. 6 bags of UT substrate with a weight of 0.560 kg avg. each, and 6 bags for the TT with a weight of 1,680 kg avg. each were assembled. This is because after the autoclave process, the fibers (TT) were moistened and compacted. On the other hand, 6 bags were filled with the control substrate that expanded perlite with a weight of 1,480 kg avg. each, 18 bags in total. In each sack 2 lettuces of the Oakleaf variety were placed, 36 plants in total.

5. Results and discussion

5.1. Identification of i-RTG SW with potential for local use from an CE perspective

Based on the classification and quantification of the i-RTG waste (Table 2), the following materials represent less than 1% of the total solid waste generated per avg year in the i-RTG: (Fig. 1): hoses (0.55 kg/year), gaskets and hose covers (0.07 kg/year), drippers and distribution boards (0.015 kg/year), leachate collection trays (9.64 kg/year), plastic sacks (perlite containers) (1.78 kg/year), film (6.41 kg/year) and inedible tomatoes, which are considered so due to diseases (pests, rot or flowering) (18.80 kg/year), and roots (97.35 kg/year). Since the aforementioned materials are not

generated consistently and their volumes are not consequential, they were not considered to have the potential to be taken advantage of locally. The metallic waste, which comes in large part from the structure of the greenhouse, was also not considered to be materially relevant, due to the low volume generated per avg. year. On the other hand, the following materials represent the largest volumes of SW from the i-RTG: expanded perlite (207.06 kg/year) which is the most generated inorganic fraction, only one bag weighs 12 kg after use (wet perlite); leaf and branch biomass from pruning (226.09 kg/year), which begins to generate approximately 30 days from the start of cultivation; leaves and branches after harvest (204.05 kg/year); and stems that measure 6 m long avg. (129.05 kg/year) generated in just one day at the end of the harvest.

In general, the results show that 1.1 kg of SW per 1 kg of tomato production are generated, of which the largest portion of the waste is organic and represents 0.8 kg per 1 kg of tomato production. However, the frequency of its generation varies according to the type of biomass. That is, both pruning (branches and leaves) and inedible tomatoes are generated in small quantities throughout cultivation, so that their management does not represent a major problem for cities, unlike the stems of tomato plants that, due to the large volumes generated after harvest (can be reviewed in Supplementary data) and their woody quality when dried (see Fig. 2). On the other hand, when the tomato stems are dried, they lose between 80 and 86% moisture (can be reviewed in the Supplementary data) but retain their length of 6 m long avg.

Table 2. i-RTG solid waste flow

Element	Material	Production per avg year (kg)	Per kg of tomatoes production (kg)	Kg per m^2 of crop area (kg)	Kg per 171 tomato plants (kg)
Inorganic outputs					
Substrate	Expanded perlite	207.06	0.143	2.455	1.21
	HDPE	1.78	0.001	0.021	0.01
Pump + pressure switch	Cast iron	0.88	0.001	0.010	0.01
Nutrient tank	PE	0.81	0.001	0.010	0.00
Water tank	PE	1.50	0.001	0.018	0.01
Covering plastic	LDPE	0.70	0.000	0.008	0.00
Supporting tray	EPS	9.17	0.006	0.109	0.05

Other elements <0.5 % of production per avg year	Steel, HDPE, PP, PVC, LDPE, PE, EPS	2.95	0.002	0.035	0.02
Total inorganic outputs per year avg		**224.85**	**0.155**	**2.666**	**1.31**
Organic outputs					
Pruning biomass	Branches and leaves	226.09	0.156	2.681	1.32
Biomass at the end of the crop	Branches and leaves	204.05	0.140	2.419	1.19
Tomato stems	Main Stems	129.05	0.089	1.530	0.75
Total organic outputs per year avg		**559.19**	**0.385**	**6.630**	**3.27**

HDPE= High density polyethylene, PE= Polyethylene, LDPE= Low density polyethylene, EPS= Expanded polystyrene, PP= Polypropylene, PVC= Polyvinyl chloride.

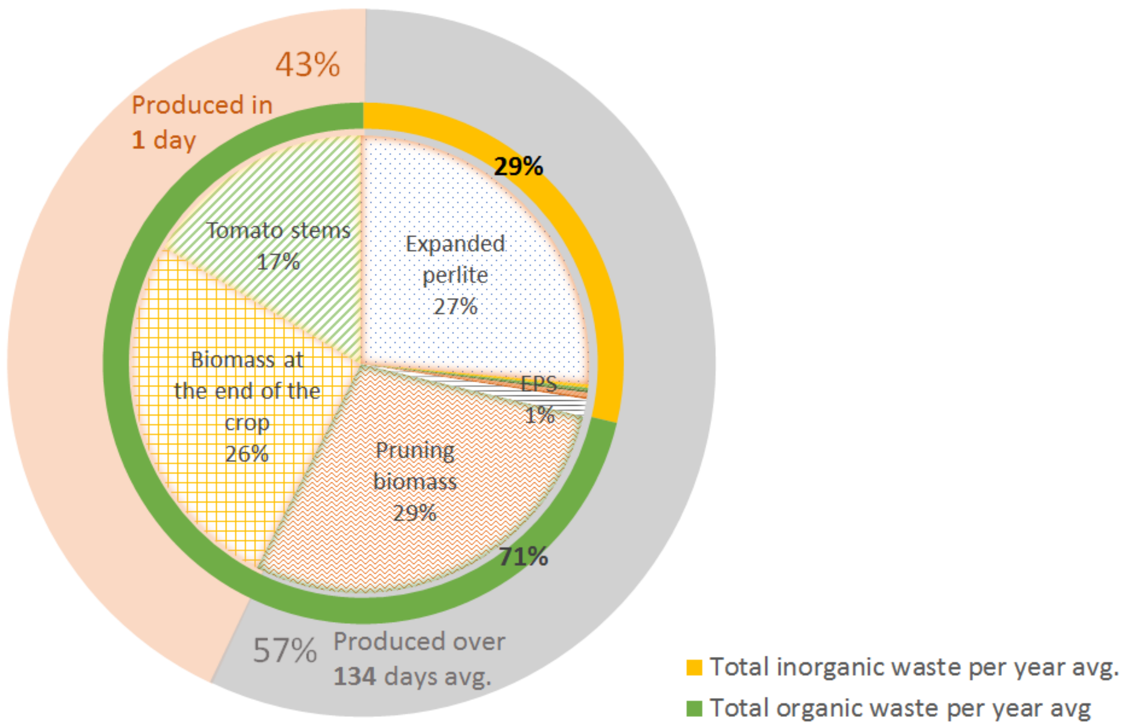

Fig. 2. Percentages of generation of iRGT SW by materials and the timing of its generation

According to the different types of i-RTG SW and regarding the best process to manage it, we have that the recycling of plastics is a simple process that allows the use of this material several times without the need to extract new raw materials with the reduction of the environmental impact that it implies. In addition, with simple recycling processes, composite materials or composites can be developed to which natural fibers can be incorporated as polymer reinforcement to improve resistance, stiffness or degradation properties. On the other hand, it is necessary that the plastic is dry and clean to process it mechanically, which increases the costs to compete in the market (Antón & Muñoz, 2013). However, it is important to consider the environmental improvement involved in the recycling of plastics compared to other procedures and manage them correctly (correct separation) as a material with potential for use from the beginning. About the expanded perlite from the circular perspective, the best option for its management after its useful life of 3 to 4 years is its reuse as a substrate. Passing this time, the hot water cleaning and disinfection treatment described by H. Hanna (2005) can be used if necessary, without affecting the next crop. Speaking of biomass, as mentioned earlier, it is not managed optimally due to lack of interest in its use or recovery. Usually, it is mixed with inorganic remains such as synthetic raffia, which complicates its recovery (Callejón, Carreño, Sánchez-hermosilla, & Pérez, 2010; Dupuis, 2012) speaking in general of the biomass generated in the agricultural industry. On the other hand, since the volume of biomass generated in UA is smaller, there has not been much interest in looking for other ways to take advantage of them in addition to composting which is the most widespread management.

And as mentioned above, home composting is an option that has good results with environmental advantages (Colón et al., 2010; Martínez-Blanco et al., 2010; Quirós et al., 2014) unlike industrial composting for this case. However, in the process to prepare compost, gases that generate environmental impact are released as mentioned by Sanjuan-Delmás (2018) for the case of biomass generated in i-RTG.

Based on the aforementioned results regarding the i-RTG SW flow generated and the type of management possible for each type, it was decided to prioritize biomass over inorganic SW and the substrate. In particular, the tomato stems were chosen for local use because, in addition to the large volume that is generated only on the last day of cultivation, when the stems are dried, they become a woody material more difficult to manage within the cities unlike the leaves and branches that are pruned regularly and that their total volume is managed fractionally throughout the crop and can be easily disintegrated when dried.

5.2. Proposal for the local use of i-RTG tomato stems

Unlike crops outside cities, where organic waste can be directly re-incorporated into the soil, which is the most economically and environmentally efficient option, within cities this would not be possible. One of the local managements that can be used within cities to take advantage of biomass, particularly the stems of tomato plants, is composting as mentioned above. For the preparation of compost at the local level (home composting), two types of organic waste are normally used, one part is generally made up of fruit, raw vegetables and other food remains (LFV) and the other part is Pruning waste (PW) such as stems and branches, the latter function as bulking agents to provide sufficient porosity, to reduce humidity when necessary and prevent the generation of leachate during the composting process. The ratio varies between 0.8:1 and 1.3:1 respectively (Colón et al., 2010; Martínez-Blanco et al., 2010; Quirós et al., 2014). The first step is to shred the PW fraction to adjust the particle size since, due to its composition, it takes longer to degrade than the LFV fraction. This step for home composting is the only one that involves energy consumption (28 kW/h per ton of PW avg corresponding to 4.2 h/t OFMSW)(Martínez-Blanco et al., 2010).On the other hand, the greatest impact generated in home composting is related to the emission of volatile organic compounds, nitrous oxide, methane and ammonia gases that are released during the manufacturing process and together represent 99% of the total emissions (Martínez-Blanco et al., 2010; Quirós et al., 2014). In this case, the stems of tomato plants correspond to the fraction of PW and for the purpose of our investigation, their use without mixing it with other types of waste would not work to compost, so its use was considered to be used as a substrate for soilless crop. The process for the preparation of substrate requires as the only process, the shredded of the stems. This is essentially the first step of composting. Therefore, speaking only of the environmental impact generated during the compost process, without considering the stage of use, the preparation of substrate implies a reduction in the environmental impact compared to home composting.

5.3. Experimental crops with tomato stems as substrate

In our case, the results of the use of tomato stems as a substrate in a soilless lettuce crops, initially were not very good with respect to the leachate values of the electrical conductivity (EC), since they were very high. However, over time these values decreased to reach values similar to those of the control substrate, which improved the conditions of lettuce production as can be seen below for each case.

5.3.1. Crop 1

In the first lettuce crop using the tomato stems as a substrate, we observed that in general between the performance of the TT and UT substrates there was not much difference. However, for EC (mS/cm) at the beginning of the crop, TT began with 12.47 and UT with 10.47 while the perlite used as the control substrate (P) was 1.64 and was maintained with a value of 1.80 avg. throughout the crop, with a deviation of 0.18. On the other hand, TT and UT gradually decreased until reaching very similar values to the control at the end of the culture, TT with 2.23 and UT with 2.97. The pH values for the control were 7.87 avg. with a deviation of 0.25 during the whole crop, TT with 7.64 and a deviation of 0.19 and UT with 7.70 and a deviation of 0.19. So during the whole crop there was no great variation for the pH levels. Regarding production, on average the fresh air weight per lettuce for P was 392 g, for TT it was 103 g and UT was 136 g. The weight of the fresh root part of P was 0.06 g, TT was 0.07 g and UT 0.06 g.

5.3.2. Crop 2

In the second lettuce crop using the same tomato stems as a substrate as in the first crop, we observed in general that the performance of the TT and UT substrates was very similar. We start from more stable levels than in the first crop. For EC (mS/cm) at the beginning of the TT crop, it started with 1.75 and UT with 1.87 while P was 1.57 and remained with an average value of 1.68 during the whole crop with a deviation of 0.14. On the other hand, TT on average had 2.20 with a deviation of 0.28 and a UT 2.45 with a deviation of 0.48. At the end of the crop TT had 2.29 and UT 2.19. The pH values for P were 7.57 avg. with a deviation of 0.35 throughout the crop, those of TT of 8.13 with a deviation of 0.42 and UT of 8.15 with a deviation of 0.22. So, during the whole crop there was no great variation for the pH levels.

Regarding production, on average the fresh air weight per lettuce for P was 354 g, for TT it was 195 g and UT was 211 g. The weight of the fresh root part of P was 58 g, TT was 148 g and UT 196 g.

5.3.3. Wash treatment

After carrying out the wash treatment of the TT6 and UT6 samples, we realized that the high levels of EC progressively decrease until reaching stable levels similar to those of tap water (0.57 mS/cm avg) along of 15 days according to the system we use described in Supplementary data. However, to reach levels similar to P (between 1.66 and 1.68 mS/cm), TT6 needed approximately 3 days starting with a value of 3.9 mS/cm and UT6 approximately 4 days, starting with 8.1 mS/cm. On the other hand, regarding the pH values, TT started with 7.2 and remained on average at 6.8 throughout the 15 days. UT started with 6.8 and on average 6.08 during the 15 days so there was no big difference. Regarding the pH of the tap water, it remained on average at 7.32, so the values were always very similar to TT and UT. However, it must be considered that the pH of P is between 7.57 and 7.87 due to the use of nutrients in irrigation. After the washing treatment, the substrate samples TT6 and UT6 were not reincorporated into the lettuce culture, so there is no production data for said samples. However, with respect to the EC and pH values, the production results of the crop 2 can be taken as a reference.

In general, to have a better and more stable substrate performance, a good option is to perform a prewash treatment to decrease EC levels. It is also noted that there is no relevant difference between TT and UT substrates with respect to EC and pH values. In fact, regarding the production of lettuce it had better TT performance than UT, so we discarded the use of autoclave as a pretreatment in addition to saving energy.

6. Conclusions and future work

According to the results of the classification and quantification of the i-RTG SW obtained and based on the literature found on the management options for each type of SW, it was identified that biomass is the fraction of SW that has the greatest potential to be used locally from a circular economy perspective, particularly the stems of tomato plants. In addition, biomass is the most critical type of SW if not managed properly due to their organic composition. Tomato stems when dried at room temperature for 3 months lose between 80 and 86% moisture and acquire a woody appearance. Based on the literature, it is observed that a good option for the use of stems is home composting that generates less environmental impact than industrial composting (municipal management). However, the preparation of substrate with tomato stems would generate less environmental impact than compost according to the process for its elaboration. Therefore, it was determined to test the tomato stems as a substrate using them in 2 lettuce crops.

When performing the first experimental soilless lettuce crop using tomato stems as a substrate, we observe that the EC values are high with respect to the control substrate that was the perlite. Therefore, we performed substrate wash treatment with good results that we could verify in the second crop with the same substrate, the EC values decreased to levels similar to the control substrate. In addition, the results of the production of the second crop were better than those of the production of the first with respect to the aerial and root weight of the lettuces.

It would be interesting for future research to mix the tomato stems substrate with the expanded perlite considering that it is the most used type of substrate. This would also allow replacing the perlite that can be lost when handling or washing the treatment, enriching the substrate with nutrients. On the other hand, considering that the i-RTG of the case study works as part of the metabolism of the building, taking advantage of the flow of water and gases, it could also be considered in the future to integrate the rest of the organic waste from the building to produce substrate with better performance or even compost. In addition to its use as a substrate, with respect to the literature, several interesting techniques were identified for the use of tomato stems, including compression with temperature or with a natural binder to create pots, bricks, panels or use them as fibers of reinforcement in polymeric matrices to create bio-plastics. However, in order to take advantage of them more efficiently, it is essential to know the physical, chemical and mechanical properties of the material.

It would be important, in addition to closing the cycles taking advantage of the biomass to increase the environmental benefits within the i-RTG developing substrate or creating an ecomaterial, to contemplate the new needs that may arise if we consider the increased number of RTG and its wastes. In this way, a problem could be foreseen about the management of excess organic waste within cities. It would also be important to take measures from the planning and assembly of the RTG, consider the end of the useful life of the facilities, the auxiliary equipment used and the inorganic and organic SW flows that are generated, in which case it would be convenient to start calling by-products.

Acknowledgement

The authors are grateful for the financial support provided by the Mexican Council of Science and Technology (CONACYT) along with the Secretariat of Energy (SENER) (Mexico), through the grant awarded for the completion of the PhD. We also recognize the financial support of the Spanish Ministry of Economy and Competitiveness (MINECO) for the financial support of the research projects Fertilecity (CTM2016-75772-C3-1-R, AEI/FEDER, UE) and "María de Maeztu" program for Units of Excellence in R&D (MDM-2015-0552). They also thank Felipe Agustín Parada Molina for the advice in the agronomy area, Verónica Arcas Pilz for the help in the realization of the experimental crops and to Gerard Pidemunt Moragas for his help in the characterization of the stems as a substrate.

Appendix A. Supplementary data

References

Acuña, R. A., Bonachela, S., Magán, J. J., Marfà, O., Hernández, J. H., & Cáceres, R. (2013). Reuse of rockwool slabs and perlite grow-bags in a low-cost greenhouse: Substrates' physical properties and crop production. *Scientia Horticulturae*, *160*, 139–147. https://doi.org/10.1016/j.scienta.2013.05.031

Amigó, V., Salvador, M. D., Sahuquillo, O., Llorens, R., & Martí, F. (2008). Valorización de residuos de fibras vegetales como refuerzo de plásticos industriales. In *I Simposio Iberoamericano de Ingeniería de Residuos* (pp. 23–24). Castellón.

Amigó, Vicente, Salvador, M. D., & Sahuquillo, O. (2008). Aprovechamiento de residuos de fibras naturales como elementos de refuerzo de materiales poliméricos. *Quinto Congreso Internacional De Fibras Naturales*, (November 2016).

Anton, A., Montero, J. I., Munoz, P., & Castells, F. (2005). LCA and tomato production in Mediterranean greenhouses. *International Journal of Agricultural Resources, Governance and Ecology*, *4*(2), 102. https://doi.org/10.1504/IJARGE.2005.007192

Antón, A., & Muñoz, P. (2013). Integrated preventive environmental strategy in greenhouse production. In FAO (Ed.), *Good Agricultural Practices for greenhouse vegetable crops Principles for Mediterranean climate areas* (pp. 303–354). Rome.

Burés, S., Martínez, X., López, M., Cáceres, R., & Marfà, O. (2014). Substrats per a cultius fora de sòl en horticultura: Materials alternatius per a la preparació de substrats. Dossier Tècnic nº74. *Departament d'Agricultura, Ramaderia, Pesca, Alimentació i Medi Natural, Barcelona*.

Callejón, A. J., Carreño, A., Sánchez-hermosilla, J., & Pérez, J. (2010). Evaluación de impacto ambiental de centro de transformación y gestión de residuos sólidos agrícolas en la provincia de Almería (España). *Informes de La Construccion*, *62*(518), 79. https://doi.org/10.3989/ic.08.028

Camarsa, G., Toland, J., Eldridge, J., Potter, J., Nottingham, S., Geater, M., … Martínez, E. (2017). *LIFE and circular economy*. https://doi.org/10.2779/29436

CEDEX, M. de F. (2013). *Residuos plásticos* (Diciembre No. 6.1). Retrieved from http://www.cedexmateriales.es/upload/docs/es_RESIDUOSPLASTICOSDIC2013.pdf

Colón, J., Martínez-Blanco, J., Gabarrell, X., Artola, A., Sánchez, A., Rieradevall, J., &

Font, X. (2010). Environmental assessment of home composting. *Resources, Conservation and Recycling*, *54*(11), 893–904. https://doi.org/10.1016/j.resconrec.2010.01.008
De Boodt, M., Verdonck, O., & Cappaert, I. (1974). METHOD FOR MEASURING THE WATERRELEASE CURVE OF ORGANIC SUBSTRATES. *Acta Horticulturae*, (37), 2054–2063. https://doi.org/10.17660/ActaHortic.1974.37.20
Demertzi, M., Sierra-Pérez, J., Paulo, J. A., Arroja, L., & Dias, A. C. (2017). Environmental performance of expanded cork slab and granules through life cycle assessment. *Journal of Cleaner Production*, *145*, 294–302. https://doi.org/10.1016/j.jclepro.2017.01.071
Dupri, I. (2006). Estimación de los residuos agrícolas generados en la isla de Tenerife, 3–20.
Dupuis, I. (2012). Producción y consumo sostenibles y residuos agrarios. Madrid: Ministerio de Agricultura, Alimentación Y Medio Ambiente Secretaría. https://doi.org/10.1007/s13398-014-0173-7.2
Energía, A. E. de la. (2013). Residuos de industrias agrícolas. Extremadura: Agencia Extremeña de la Energía. Retrieved from http://www.agenex.net/images/stories/deptos/residuos-ind-agr.pdf
EU. (2015). EU Action Plan on a Circular Economy COM (2015) 614/2 adopted on 2.12.2015.
European Parliament. (2008). On Waste and Repealing Centain Directives. *Journal of the European Union*, 3–30. https://doi.org/2008/98/EC.; 32008L0098
FAO, FIDA, OMS, PMA, & UNICEF. (2017). *El estado de la seguridad alimentaria y la nutrición en el mundo 2017.* Roma. Retrieved from http://www.fao.org/3/a-I7695s.pdf
Hanna, H. Y. (2005). Properly Recycled Perlite Saves Money, Does Not Reduce Greenhouse Tomato Yield, and Can Be Reused for Many Years H.Y. *Technology & Prod Uct Reports*, *15*(June), 342–345.
Hubbe, M. A., Nazhad, M., & Sánchez, C. (2010). Composting as a way to convert cellulosic biomass and organic waste into high-value soil amendments: A review. *BioResources*, *5*(4), 2808–2854. https://doi.org/10.15376/biores.5.4.2808-2854
Huerta, O., López, M., & Soliva, M. (2010). *Procés de compostatge: Caracterització de mostres*. *Diputació de Barcelona*.
Jústiz-Smith, N. G., Virgo, G. J., & Buchanan, V. E. (2008). Potential of Jamaican banana, coconut coir and bagasse fibres as composite materials. *Materials Characterization*, *59*(9), 1273–1278. https://doi.org/10.1016/j.matchar.2007.10.011
Korhonen, J., Nuur, C., Feldmann, A., & Birkie, S. E. (2018). Circular economy as an essentially contested concept. *Journal of Cleaner Production*, *175*, 544–552. https://doi.org/10.1016/j.jclepro.2017.12.111
Kotwica, Ł., Pichór, W., Kapeluszna, E., & Różycka, A. (2017). Utilization of waste expanded perlite as new effective supplementary cementitious material. *Journal of Cleaner Production*, *140*, 1344–1352. https://doi.org/10.1016/j.jclepro.2016.10.018
L. Señas, Valea, J., P. Maiza, & Marfil, S. (2004). Durabilidad de hormigones livianos elaborados con perlita expandida Expanded perlite light weight concrete durability. *Materiales de Construcción*, *25*(3).
Li, X., Chen, H., Liu, L., Lu, Z., Sanjayan, J. G., & Duan, W. H. (2016). Development of granular expanded perlite/paraffin phase change material composites and prevention of leakage. *Solar Energy*, *137*, 179–188.

https://doi.org/10.1016/j.solener.2016.08.012
Llorach-Massana, P., Lopez-Capel, E., Peña, J., Rieradevall, J., Montero, J. I., & Puy, N. (2017). Technical feasibility and carbon footprint of biochar co-production with tomato plant residue. *Waste Management*, *67*, 121–130. https://doi.org/10.1016/j.wasman.2017.05.021
Llorach-Massana, P., Muñoz, P., Riera, M. R., Gabarrell, X., Rieradevall, J., Montero, J. I., & Villalba, G. (2017). N2O emissions from protected soilless crops for more precise food and urban agriculture life cycle assessments. *Journal of Cleaner Production*, *149*, 1118–1126. https://doi.org/10.1016/j.jclepro.2017.02.191
Llorach-Massana, P., Peña, J., Rieradevall, J., & Montero, J. I. (2016). LCA & LCCA of a PCM application to control root zone temperatures of hydroponic crops in comparison with conventional root zone heating systems. *Renewable Energy*, *85*, 1079–1089. https://doi.org/10.1016/j.renene.2015.07.064
Llorach Massana, P. (2017). *Mitigating the environmental impacts of Urban Agriculture: innovative materials, GHG emissions analysis and new by-products*. Retrieved from https://ddd.uab.cat/record/186428
Martínez-Blanco, J., Colón, J., Gabarrell, X., Font, X., Sánchez, A., Artola, A., & Rieradevall, J. (2010). The use of life cycle assessment for the comparison of biowaste composting at home and full scale. *Waste Management*, *30*(6), 983–994. https://doi.org/10.1016/j.wasman.2010.02.023
Martínez, F. . (1992). Propuesta de metodología para la determinación de las propiedades físicas de los sustratos. *Actas de Horticultura*, *11*, 55–66. Retrieved from https://www.scopus.com/record/display.uri?eid=2-s2.0-0001984595&origin=inward&txGid=df78de57c5323ccea7a4e61a59263fb0
Martínez Rey, M. D. (2014). *Formación de PCDD/Fs y otros contaminantes en procesos térmicos: aprovechamiento de biomasa y motores de combustión interna*. Universidad de Alicante.
Mendoza, D. de J. (2010). *Vermicompost y compost de residuos hortícolas como componentes de sustratos para la producción de planta ornamental y aromática. Caracterización de los materiales y respuesta vegetal*. Universitat Politècnica de València, Valencia (Spain). https://doi.org/10.4995/Thesis/10251/8685
MITECO, & INE. (2016). Memoria Anual De Generación Y Gestión De Residuos Residuos De Competencia Municipal . 2016.
Muñoz, P., Antón, A., Montero, J. I., & Castells, F. (2003). Using LCA for the Improvement of Waste Management in Greenhouse Tomato Production. *October*, *II*(92).
Nisticò, R., Evon, P., Labonne, L., Vaca-Medina, G., Montoneri, E., Vaca-Garcia, C., & Negre, M. (2017). Post-harvest tomato plants and urban food wastes for manufacturing plastic films. *Journal of Cleaner Production*, *167*, 68–74. https://doi.org/10.1016/j.jclepro.2017.08.160
Piezer, K., Petit-Boix, A., Sanjuan-Delmás, D., Briese, E., Celik, I., Rieradevall, J., … Apul, D. (2019). Ecological network analysis of growing tomatoes in an urban rooftop greenhouse. *Science of the Total Environment*, *651*(September), 1495–1504. https://doi.org/10.1016/j.scitotenv.2018.09.293
Piorr, A., Zasada, I., Doernberg, A., Zoll, F., & Ramme, W. (2018). *Research for AGRI Committee - Urban and Peri-urban Agriculture in the EU*. Retrieved from http://www.europarl.europa.eu/RegData/etudes/STUD/2018/617468/IPOL_STU(2018)617468_EN.pdf
Pons, O., Nadal, A., Sanyé-Mengual, E., Llorach-Massana, P., Cuerva, E., Sanjuan-Delmàs, D., … Rovira, M. R. (2015). Roofs of the Future: Rooftop Greenhouses to

Improve Buildings Metabolism. *Procedia Engineering*, *123*, 441–448. https://doi.org/10.1016/j.proeng.2015.10.084
Puri, V., & Caplow, T. (2009). *100% Renewable Energy autonomy in action - Chapter 12. World*. Earthscan. Retrieved from https://books.google.es/books?hl=es&lr=&id=HllZW4ZSheUC&oi=fnd&pg=PA229&dq=Puri+and+Caplow,+2009&ots=rK9h1QmPI5&sig=3gBbhqpnvl0Io--zhB3t8frL-Aw#v=onepage&q&f=false
Quintero, M. F., González M., C. A., & Guzmán P., J. M. (2011). Sustratos para cultivos hortícolas y flores de corte. In E. U. N. de Colombia (Ed.) (pp. 79–108). Bogotá.
Quirós, R., Villalba, G., Muñoz, P., Colón, J., Font, X., & Gabarrell, X. (2014). Environmental assessment of two home composts with high and low gaseous emissions of the composting process. *Resources, Conservation and Recycling*, *90*, 9–20. https://doi.org/10.1016/j.resconrec.2014.05.008
Ros, M. (2012). Salidas valorizables de los residuos y subproductos orgánicos de la industria de los transformados de frutas y hortalizas. *Valorización de Residuos*, *130*, 2–9.
Sanjuan-Delmás, D., Llorach-Massana, P., Nadal, A., Ercilla-Montserrat, M., Muñoz, P., Montero, J. I., … Rieradevall, J. (2018). Environmental assessment of an integrated rooftop greenhouse for food production in cities. *Journal of Cleaner Production*, *177*, 326–337. https://doi.org/10.1016/j.jclepro.2017.12.147
Sanjuan-Delmás, D., Llorach-Massana, P., Nadal, A., Sanyé-Mengual, E., Petit-Boix, A., Ercilla-Montserrat, M., … Pons, O. (2018). Improving the Metabolism and Sustainability of Buildings and Cities Through Integrated Rooftop Greenhouses (i-RTG) (pp. 53–72). Springer, Cham. https://doi.org/10.1007/978-3-319-67017-1_3
Sanjuan Delmás, D. (2017). *Environmental assessment of water supply: cities and vertical farming buildings*. Universidad Autónoma de Barcelona.
Sanyé-mengual, E., Llorach-masana, P., Sanjuan-, D., Oliver-solà, J., Josa, A., Montero, J. I., & Rieradevall, J. (2014). The ICTA-ICP Rooftop Greenhouse Lab (RTG-Lab): closing metabolic flows (energy, water, CO2) through integrated Rooftop Greenhouses, 692–701. Retrieved from https://www.researchgate.net/profile/Esther_Sanye-Mengual/publication/275956813_The_ICTA-ICP_Rooftop_Greenhouse_Lab_RTG-Lab_closing_metabolic_flows_energy_water_CO_2_through_integrated_Rooftop_Greenhouses/links/554b49f40cf29752ee7c532b.pdf
Sanye-Mengual, E., Oliver-Sola, J., Montero, J. I., & Rieradevall, J. (2015). An environmental and economic life cycle assessment of rooftop greenhouse (RTG) implementation in Barcelona, Spain. Assessing new forms of urban agriculture from the greenhouse structure to the final product level. *International Journal of Life Cycle Assessment*, *20*(3), 350–366. https://doi.org/10.1007/s11367-014-0836-9
Sanyé-Mengual, E, Oliver-Solà, J., Antón, A., Ignacio Montero, J., & Rieradevall, J. (2014). Environmental assessment of urban horticulture structures: implementing Rooftop Greenhouses in Mediterranean cities. *Proceedings of the 9th International Conference on Life Cycle Assessment in the Agri-Food Sector Environmental*, 1169–1178.
Sanyé-Mengual, Esther, Anguelovski, I., Oliver-Solà, J., Montero, J. I., & Rieradevall, J. (2016). Resolving differing stakeholder perceptions of urban rooftop farming in Mediterranean cities: promoting food production as a driver for innovative forms of urban agriculture. *Agriculture and Human Values*, *33*(1), 101–120.

https://doi.org/10.1007/s10460-015-9594-y
Sanyé-Mengual, Esther, Cerón-Palma, I., Oliver-Solà, J., Montero, J. I., & Rieradevall, J. (2015). Integrating horticulture into cities: A guide for assessing the implementation potential of rooftop greenhouses (RTGs) in industrial and logistics parks. *Journal of Urban Technology*, *22*(1), 87–111. https://doi.org/10.1080/10630732.2014.942095
Satyanarayana, K. G., Arizaga, G. G. C., & Wypych, F. (2009). Biodegradable composites based on lignocellulosic fibers-An overview. *Progress in Polymer Science (Oxford)*, *34*(9), 982–1021. https://doi.org/10.1016/j.progpolymsci.2008.12.002
Schettini, E., Santagata, G., Malinconico, M., Immirzi, B., Scarascia Mugnozza, G., & Vox, G. (2013). Recycled wastes of tomato and hemp fibres for biodegradable pots: Physico-chemical characterization and field performance. *Resources, Conservation and Recycling*, *70*, 9–19. https://doi.org/10.1016/j.resconrec.2012.11.002
Schiavoni, S., D'Alessandro, F., Bianchi, F., & Asdrubali, F. (2016). Insulation materials for the building sector: A review and comparative analysis. *Renewable and Sustainable Energy Reviews*, *62*, 988–1011. https://doi.org/10.1016/j.rser.2016.05.045
Sevigné-Itoiz, E., Gasol, C. M., Rieradevall, J., Gabarrell, X., Sevigné-Itoiz, E., Gasol, C. M., … Gabarrell, X. (2015). Contribution of plastic waste recovery to greenhouse gas (GHG) savings in Spain. *Waste Management*, *46*, 557–567. https://doi.org/10.1016/j.wasman.2015.08.007
Sierra-Pérez, J., García-Pérez, S., Blanc, S., Boschmonart-Rives, J., & Gabarrell, X. (2018). The use of forest-based materials for the efficient energy of cities: Environmental and economic implications of cork as insulation material. *Sustainable Cities and Society*, *37*, 628–636. https://doi.org/10.1016/j.scs.2017.12.008
Sierra-Pérez, Jorge, Boschmonart-Rives, J., Dias, A. C., & Gabarrell, X. (2016). Environmental implications of the use of agglomerated cork as thermal insulation in buildings. *Journal of Cleaner Production*, *126*, 97–107. https://doi.org/10.1016/J.JCLEPRO.2016.02.146
Specht, K., Siebert, R., Hartmann, I., Freisinger, U. B., Sawicka, M., Werner, A., … Dierich, A. (2014). Urban agriculture of the future: An overview of sustainability aspects of food production in and on buildings. *Agriculture and Human Values*, *31*(1), 33–51. https://doi.org/10.1007/s10460-013-9448-4
Taherishargh, M., Belova, I. V., Murch, G. E., & Fiedler, T. (2014). Low-density expanded perlite–aluminium syntactic foam. *Materials Science and Engineering: A*, *604*, 127–134. https://doi.org/10.1016/j.msea.2014.03.003
Thomaier, S., Specht, K., Henckel, D., Dierich, A., Siebert, R., Freisinger, U. B., & Sawicka, M. (2015). Farming in and on urban buildings: Present practice and specific novelties of Zero-Acreage Farming (ZFarming). *Renewable Agriculture and Food Systems*, *30*(Special Issue 01), 43–54. https://doi.org/10.1017/S1742170514000143
United Nations. (2018). World Urbanization Prospects: The 2018 Revision. *United Nations Economic & Social Affairs*, 1–2. Retrieved from https://population.un.org/wup/Publications/Files/WUP2018-KeyFacts.pdf
Urrestarazu, M., Suárez-Estrella, F., & Mazuela, P. (2005). Reutilización de los Residuos Derivados De La Industria Hortícola. *Agronegocios, Vida Rural*, 26–29.
Vega-Baudrit, J., Delgado-Montero, K., & Madrigal-Carballo, S. (2011). Biodegradable

Polyurethanes From Sugar Cane Biowastes. *Cellulose Chemistry and Technology*, *45*(7–8), 507–514.

Yepes, S. M., Naranjo, ; Lina Johana Montoya, & Sánchez, F. O. (2008). Valorización de residuos agroindustriales – frutas – en Medellín y el Sur del Valle del Aburrá, Colombia, *61*(1), 4422–4431. Retrieved from http://www.scielo.org.co/pdf/rfnam/v61n1/a18v61n1.pdf?