Hydroponic cultivation: life cycle assessment of substrate choice

Giuliana Vinci
Sapienza University of Rome, Rome, Italy, and
Mattia Rapa
Department of Management, Sapienza University of Rome, Rome, Italy

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Abstract

Purpose – Nowadays, hydroponic cultivation represents a widely used agricultural methodology. The purpose of this paper is to study comparatively on hydroponic substrates. This study is highlighting the best substrate to be involved in hydroponic systems, considering its costs and its sustainability.

Design/methodology/approach – Seven substrates were evaluated: rock wool, perlite, vermiculite, peat, coconut fibres, bark and sand. Life cycle assessment (life cycle inventory, life cycle impact assessment (LCIA) and life cycle costing (LCC)) was applied to evaluate the environmental and economic impact. Through the results of the impacts, the carbon footprint of each substrate was calculated.

Findings – Perlite is the most impacting substrate, as highlighted by LCIA, followed by rock wool and vermiculite. The most sustainable ones, instead, are sand and bark. Sand has the lower carbon footprint (0.0121 kg CO_2 eq.); instead, bark carbon footprint results in one of the highest (1.1197 kg CO_2 eq.), while in the total impact analysis this substrate seems to be highly sustainable. Also for perlite the two results are in disagreement: it has a high total impact but very low carbon footprint (0.0209 kg CO_2 eq.) compared to the other substrates. From the LCC analysis it appears that peat is the most expensive substrate (€6.67/1,000 cm^3), while sand is the cheaper one (€0.26/1,000 cm^3).

Originality/value – The LCA and carbon footprint methodologies were applied to a growing agriculture practice. This study has highlighted the economic and environmental sustainability of seven substrates examined. This analysis has shown that sand can be the best substrate to be involved in hydroponic systems by considering its costs and its sustainability.

Keywords Life cycle assessment, Carbon footprint, Life cycle costing, Hydroponic, Life cycle impact assessment, Life cycle inventory

Paper type Research paper

1. Introduction

Hydroponics is a cultivation technique uses nutritive solutions for the plants' growth with or without the use of inert media or substrates. The "hydroponic" term comes from the Greek, hydro ὑδρο- (water) and Πόνος ponos (work). It is literally expressible as "work in water" or in the meaning of "cultivation in water" (Vogel, 2008). Nowadays, hydroponic cultivation represents an intensive agricultural production methodology. This technique requires high initial capital investments but, over time, it guarantees a rapid return of resources. Hydroponic agriculture allows a high control of the elements used, such as energy, nutrients and pesticides. This cultivation can guarantee a reduction of waste and resources used, as well as the environmental impact (Folinas *et al.*, 2006). Nevertheless, world population growth requires an increase in agricultural production. Hydroponic gives the possibility to attend through an alternative cultivation method such as those that imply off-ground production. This cultivation has some advantages: hydroponic crops can grow where there is no agricultural land available or where the soil is contaminated or where environmental temperatures are not favourable to agriculture. Therefore, the reuse of nutrients and substrates lead to a very high control of the resources, avoiding the contamination of soil and groundwater and reducing environmental pollution (Botonaki *et al.*, 2006). Moreover, substrates can easily be sterilised, allowing a minimum risk of contamination by pathogens.

This work deals with a comparative study on hydroponic substrates. Seven substrates were assessed such as rock wool, perlite, vermiculite, peat, coconut fibres, bark and sand.

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Through the life cycle assessment (LCA) evaluation was as highlighted the best substrate to be involved in hydroponic systems, by considering its costs and its sustainability. This through LCA methodology is a more responsible approach that can be integrated into the processes of "decision making" business (Johnson *et al.*, 2013).

Therefore, the effects of environmental changes led society to give more attention to the pollution impact. These effects lead to a high interest in sustainability in economic models, leaving the linear production systems logic and facilitating the transition from a linear production system to a circular production system. The circular production system generates the circular economy paradigm (Mathews and Tan, 2011), defined as an open production system in which waste is reused as resources (Preston, 2012) and emphasising the focus on the entire life cycle of products. The change in the economic vision could bring to a mitigation of the negative economic effects, through the creation of new businesses and new jobs, stimulating the transformation process of the old linear production systems and generating environmental benefits. The study through the LCA method allows comparing the production of goods, by analysing the amount of the first raw materials requests or the amount of CO_2 emissions. Currently, requests from the market have changed, consumers no longer ask for products or services they evaluate the environmental impacts (de Backer *et al.*, 2009). One of the areas in which this greater sensitivity to environmental impacts is most emphasised is in the agricultural sector, where the wastes produced are closely related to the growing food demand in perspective of world population increase (Notarnicola *et al.*, 2012). Also, in hydroponic cultivation LCA is useful to evaluate the environmental impacts of this new agricultural sector (Liaros *et al.*, 2016). Moreover, hydroponic seems to be the best solution for urban farming and for vertical farming (Boxman *et al.*, 2016). LCA was applied as a tool to evaluate the hydroponic environmental impacts of specific cities, as Lyon (Romeo *et al.*, 2018) or Bologna (Sanyé-Mengual *et al.*, 2015), or for a specific crop (Tewolde *et al.*, 2016). In addition, LCA can also evaluate if the hydroponic production has negative environmental impact compared to the conventional one (Llorach-Massana *et al.*, 2016).

To the best of our knowledge, no paper has been published on the substrate impacts evaluation. The substrate chosen can influence the types of crops, so this choice is a key step of the hydroponic implementation system (Llorach-Massana *et al.*, 2016). Therefore, an economic and environmental evaluation of the single substrate, through the LCA, can be a useful and significant tool for farmers. Indeed, the substrate is one of the most impacting raw material used for hydroponic cultivation. The farm can achieve less environmental and economic impacts by choosing a sustainable substrate, also by re-using waste materials. Moreover, the evaluation of the substrate sustainability could be used by a legislator in order to regulate and to promote the hydroponic cultivation with specific substrates.

2. Hydroponic cultivation substrates

A substrate is a material that provides support to plants and in which the plant roots can grow. The substrates can have a smaller physical volume than the soil and, consequently, there is more space for the nutritive solution and oxygen (Rodríguez-Delfín, 2012).

These materials must be isolated from the ground, and their characteristics play an important role in plants' life cycle, such as determining the maintenance of nutrient solution right levels.

The use of substrates has been established over time, thanks to the evolution of cultivation techniques and the growing awareness of the weaknesses of soil resource (Domeño *et al.*, 2011). Therefore, substrates can resolve the continuative use of intensive cultivations that causes stress, diseases and inexorable exhaustion of these resources. There is no perfect substrate, each one has different characteristics and different advantages and disadvantages (Raviv *et al.*, 2002). The choice of a particular substrate is determined by the study of different variables, such as the type of plant, the quality of the installation of the cultivation system, the price of the material, the cost of transport, the availability of this substrate in a given area and so on (Domeño *et al.*, 2011).

The substrate aim is to produce the highest quantity of better quality products in a short time and with the lowest production costs. Therefore, this cultivation can reduce the agriculture impact on the environment (Awad *et al.*, 2017).

There are several environmental advantages in the use of substrates. The substrates can be agricultural by-products such as coconut fibres, rice husk or forest biomass, materials that could contaminate the marine environment such as algae, waste materials of human or industrial activity, such as the organic fraction of urban waste, the residues of the wood industry or coal residues (Dewir *et al.*, 2005).

Obviously, as mentioned, each substrate has disadvantages, for example, the time of reuse/recycling or the environmental impact (Fernández-Cañero *et al.*, 2018).

3. Methodology

LCA is a procedure for evaluating the environmental effects/impacts of each stage of a product or a service over the entire productive cycle (from raw material extraction through materials processing, manufacture, distribution, use, repair and maintenance and disposal or recycling). The purpose of the mechanism is to improve not only the recycling process and changes in all the product life cycle phases (production, consumption, waste management, etc.) but also the placing on the market of secondary raw materials, such as plastics, food waste, critical raw materials, construction and demolition, biomass and bio-based products. LCA is based on the analysis and determination of quantitative variables. These variables are associated with products, systems and services; they are processed by mathematical equations and composed by data that describe the life cycle (Roy *et al.*, 2009). This methodology permits to quantify the energy and materials used (inputs) and the wastes released in the environment (outputs), in order to evaluate tangible opportunities to reduce the environmental negative outputs (Koci and Trecakova, 2011).

In this work the life cycle methodology was applied. After the definition of the goals and the scopes of each case studied, it has been found that LCA consists of three stages (ISO, 2006):

- Life cycle inventory (LCI) analysis: it is the first LCA stage; this stage is regarding the collection of data and information, analysis and validation of data, by defining and studying the exact amount of input and output derived from the system studied. The results are based on the historical records obtained from the company object of our research study (Guinee, 2002).
- Life cycle impact assessment (LCIA): it provides the information to interpret the environmental significance of the comparison. In this phase, the environmental effects are quantified as consequences of physical interaction between the production system studied and the environment. Then the impact categories have been chosen in accordance with the characterisation model implemented in Simapro 8.5. The categories have been chosen for the strong relationship between electricity demand and environmental outputs linked to the systems (Pasqualino *et al.*, 2011).
- Life cycle costing (LCC): it is a valuation method that determines the overall cost of products and services, considering its entire life cycle (International Standard Organization, 2006). The analysis permits to determine the cost drivers and understand the potential cost savings that can be applied in a system, thanks to innovations of materials, processes or products, especially if different alternatives are compared and the cost-effective option can be derived. In the LCC definition methodology, the overall cost is considered with the aim of assisting the decision

makers in the choices regarding modification of some variables in the life cycle of specific products or services, for determining the most cost-efficient and competitive solutions for the production process (Auer *et al.*, 2017).

In this study, "Simapro software 8.5" was used for the calculation of specified environmental indexes, by mathematical processing of data describing the life cycle (Rapa *et al.*, 2019; Vinci *et al.*, 2019a, b).

4. Results and discussions

4.1 Goal and scope definition

The case study leads the purpose to identify the following factors:

(1) comparative study on hydroponic substrates;

(2) environmental impact derived by each substrate;

(3) costs and sustainability evaluation of each substrate; and

(4) individuation of the best substrate to be involved in hydroponic systems.

For the case study, 1,000 cm^3 of the substrate has been defined as the functional unit to analyse the environmental impacts.

4.2 Life cycle inventory

Below are listed the main types of substrate used in the soil-growing system. It is herein defined the most important characteristics of each substrate exanimated:

(1) Rock wool: this substrate was originated in Denmark and subsequently became established in other countries including the Netherlands. Rock wool has many advantages, it prevents the birth of pathogenic elements and allows the recirculation of the nutritive solution. Nowadays, the rock wool recycling is under study. It is not a biodegradable material, and it was considered a harmful waste material. However, today some practices allow its reuse, such as the production of elements for building construction or as material in soil cultivation. The main applications of this substrate are in vegetables (tomatoes, peppers, strawberries, etc.) and floriculture (roses, gerberas, etc.) cultivations. Rock wool is a mineral product from volcanic rock wool fibres (basalt). The production potential is high, it has a high capacity of aeration and easier irrigation (compared to soil irrigation). Rock wool allows greater control on pH and, therefore, better yield management. The renewal of the substratum is quite simple and profitable; however, while the soil can be exploited for several years in a continuous way, rock wool needs to be replaced at most every two years (Dannehl *et al.*, 2015).

(2) Perlite: it is established as one of the most used substrates, not only for technical advantages but also for its high availability and competitive cost. This material is an aluminium silicate of volcanic origin and is very similar to natural glass. The expanded perlite obtained is resistant, porous, and inert. Not all types of perlite can be used in agriculture, it must have some essential characteristics such as high porosity. Perlite is a natural mineral that does not require chemical treatment and does not generate hazardous waste during processing. Perlite is not harmful to humans, can be used for a long time (minimum two years) and a once its functions have been completed, it can be recycled as an insulating material (Awad *et al.*, 2017).

(3) Vermiculite: this substrate is a silicate of hydrated magnesium, aluminium and iron, less used in soil-less cultivations compared to rock wool and perlite. In general,

vermiculite is a very porous material with great water retention capacity. It suffers from physical and chemical degradation, decreasing the aeration capacity over time, and therefore, has a quite limited duration (Hoang *et al.*, 2019).

(4) Peat: organic substrate of natural origin given by vegetal fossilisation. It is formed in marshy areas due to water excess and oxygen lack. Peat reserves are limited and non-renewable and the indiscriminate use of this material is not advisable. It has excellent physical and chemical properties such as high porosity, water retention and good ability to aeration. Peat has long been used to obtain an effect of improving plant growth, but when it is used as a substrate it requires a preparation process (Haghighi *et al.*, 2016).

(5) Coconut fibre: a new material that has been introduced on the market in the last 25 years. Coconut fibre is a by-product of the coconut industry, deriving from the walnut mesocarp. Coconut fibre is a soft material with a porosity similar to peat but differs from it for higher pH values. This substrate is totally dry and does not change its volume. Furthermore, it can improve the physical and chemical characteristics of the soil and of the substrates. It has a higher lignin content which allows it great resistance to degradation, than other organic substrates.

Coconut fibre has several advantages from an agricultural, environmental and social point of view:

- Thermal inertia: the coconut fibre can absorb thermal changes better than other substrates (such as perlite and rock wool) and, therefore, can be used in "extreme" environmental conditions. However, thermal inertia can be lost in conditions of excessive and permanent humidity.
- High water retention power: it can maintain a high amount of water useful for the plant for a time longer than other substrates, without the need for continuous irrigation.
- Long life: if correctly managed, coconut fibre can also be used for more than five years.
- Relatively low density: it has a more comfortable installation than that obtainable with other substrates.
- High productivity and quality.
- Environmental benefits: this is a residue of food and textile industries, it can be reused in an ecological way. It is biodegradable and has no environmental impact during its useful life. It is a renewable resource unlike, for example, peat.
- Social advantages: it is a substratum coming from developing economies, like tropical countries (Brazil, Mexico, Sri Lanka, etc.), therefore, it can contribute to their economic growth.

There are two important differences between coconut fibre and inert substrates (such as rock wool or perlite). At first, it does not require continuous irrigation, second its organic characteristics require some attention as regard the definition of the nutritive solution (Ali, 2011).

(6) Bark: it represents between 6 and 16 per cent of a tree volume and can be of different types. If used correctly, bark can give excellent results in the agricultural field. It can be used fresh or composted; however, the fresh bark may present a lack of nitrogen and negative elements. These phytotoxicity problems can compromise the cultivation but can be eliminated thanks to the use of composting. Given the high availability, today the bark is often used instead of peat (Tyson *et al.*, 2011).

(7) Sand: it is a material of siliceous nature and variable composition, depending on the siliceous composition of the original rock. It may come from quarries (granite, basalt, etc.) or from rivers. It must be free of silt and clay to be used as a substrate, consequently it must be washed with mineral acids and the size of the particles must be included between 0.02 and 2 mm. Sand deriving from the quarries is more homogeneous and is preferred to the rivers one. It can be also added to organic substrates such as peat or bark. Although the sand has good drainage and a low water retention capacity, when it is added to other substrates, its effect varies depending on the physical properties of these. The physical properties of the sand, on the other hand, vary depending on the size of the particles and if they are smaller than 0.5 mm they have good water retention but little ventilation (Olle *et al.*, 2012).

4.3 Life cycle impact analysis

For the calculation of the environmental and social impact of production, impact categories have been defined and chosen. The environmental variables were calculated by using Simapro 8.5 software, in order to compare the results of the seven substrates studied. Table I shows the results obtained from the conversion of relevant characterisation factors of each impact category with the LCIA results (Guinee, 2002). The impact categories were divided into three main areas: environmental (global warming on terrestrial ecosystems and freshwater ecosystems, ozone formation on terrestrial ecosystems, terrestrial acidification, freshwater eutrophication, marine eutrophication, terrestrial ecotoxicity, freshwater ecotoxicity, marine ecotoxicity, land use, water consumption on terrestrial ecosystem, water consumption and aquatic ecosystems), human health (global warming, stratospheric ozone depletion, ionising radiation, ozone formation, fine particulate matter formation, human carcinogenic toxicity, human non-carcinogenic toxicity and water consumption) and economics (mineral resource scarcity and fossil resource scarcity). The division was done in accordance with the main aspects of sustainability (Vinci *et al.*, 2019a, b). The LCIA results are shown in Table I. Figure 1 shows the impacts for each substrate in the three areas, the main impact substrates were fixed at 100 and the others are expressed as a percentage of the main one, in order to achieve a better visualisation of data (International Standard Organization, 2006).

The impacts in the environmental area are expressed as species/year, a way to measure the extinction rate. There is approximately one extinction estimated per million species-years. This means that if there were a million species on Earth, one would go extinct every year, while if there were only one species, it would go extinct in one million years. In this case the main contribution was given by perlite, followed by rock wool and coconut fibre. Instead, the minor impact was given by sand and bark. The main impact of all substrates was found in the global warming category, that nowadays is a relevant and important issue of the terrestrial ecosystem. The unit for the human health impact categories was the disability-adjusted life year. It is a measure of overall disease burden, expressed as the number of years lost due to ill health, disability or early death. Even here, the major impact was given by perlite and rock wool and the minor ones by sand and bark. Also in this case, global warming is the main impact category but a great contribution was given by fine particulate matter formation. This is an important environmental problem, usually know as PM, that can cause respiratory tract illness and cancer. Even in the economic area, with USD unit, the major impacting substrates remain the same. Herein the major contribution comes from the fossil resource scarcity, mainly used for the transportation fuel (Pasqualino *et al.*, 2011).

After the impact categories analysis, the total impact of each substrate was calculated to highlight the sustainability of the substrates. The impact percentage of each substrate was

Impact categories	Vermiculite	Bark	Coconut fibre	Peat	Perlite	Rock wool	Sand
Enviromental (species/yr)							
Global warming, terrestrial ecosystems	1,27E-08	5,09E-10	6,31E-09	4,37E-10	3,09E-08	2,69E-08	2,90E-10
Global warming, freshwater ecosystems	3,46E-13	1,39E-14	1,72E-13	1,19E-14	8,42E-13	7,35E-13	7,92E-15
Ozone formation, terrestrial ecosystems	4,24E-10	4,78E-11	9,68E-11	6,53E-12	4,26E-10	7,30E-12	9,10E-12
Terrestrial acidification	1,05E-09	3,57E-11	3,97E-10	1,46E-11	1,56E-09	1,65E-09	1,22E-11
Freshwater eutrophication	1,13E-11	0	1,02E-10	7,78E-13	3,31E-11	1,95E-13	3,03E-13
Marine eutrophication	1,84E-15	1,82E-16	3,21E-12	7,37E-17	4,47E-15	2,36E-14	5,05E-17
Terrestrial ecotoxicity	1,12E-11	4,35E-15	1,11E-11	3,22E-13	1,87E-11	1,30E-12	1,02E-12
Freshwater ecotoxicity	1,76E-13	7,80E-14	4,11E-12	4,28E-15	3,39E-13	4,02E-14	1,88E-14
Marine ecotoxicity	4,55E-10	7,62E-11	9,46E-10	9,13E-12	7,65E-10	2,01E-10	4,46E-11
Land use	1,67E-10	0	1,71E-08	9,51E-12	4,41E-10	0	6,20E-12
Water consumption, terrestrial ecosystem	1,68E-11	0	8,28E-12	8,46E-12	1,09E-10	2,14E-11	1,94E-11
Water consumption, aquatic ecosystems	7,52E-16	0	3,71E-16	3,79E-16	4,87E-15	9,56E-16	8,70E-16
Total	1,48E-08	6,69E-10	2,50E-08	4,87E-10	3,42E-08	2,88E-08	3,83E-10
Human health (DALY)							
Global warming	6,33E-06	2,54E-07	3,15E-06	2,19E-07	1,54E-05	1,35E-05	1,45E-07
Stratospheric ozone depletion	3,42E-10	1,06E-11	9,73E-09	1,40E-11	7,28E-10	4,80E-10	1,04E-11
Ionising radiation	3,12E-10	0	5,95E-10	1,65E-11	3,62E-10	2,54E-09	1,30E-11
Ozone formation	2,97E-09	3,36E-10	6,74E-10	4,55E-11	2,97E-09	3,20E-11	6,31E-11
Fine particulate matter formation	1,08E-06	3,20E-08	2,47E-07	2,59E-08	1,73E-06	1,12E-06	1,61E-08
Human carcinogenic toxicity	5,17E-07	5,06E-10	1,50E-08	2,39E-08	1,01E-06	2,50E-08	2,56E-08
Human non-carcinogenic toxicity	7,51E-07	1,74E-07	1,73E-06	1,41E-08	1,19E-06	3,32E-07	7,93E-08
Water consumption	2,76E-09	0	1,36E-09	1,39E-09	1,79E-08	3,51E-09	3,20E-09
Total	8,69E-06	4,61E-07	5,16E-06	2,84E-07	1,94E-05	1,49E-05	2,69E-07
Economic (USD)							
Mineral resource scarcity	0,013294	0	0,000136	7,26E-06	0,002345	0,00063	8,84E-06
Fossil resource scarcity	0,037031	0,002978	0,021203	0,035074	0,062243	0,066385	0,001419616
Total	0,050324	0,002978	0,02134	0,035082	0,064587	0,067015	0,001428

Table I. Substrate life cycle impact analysis for each impact categories

considered, and it was weighing with the following formula:

$$\text{Total impact} = (T.En. \times 0.33) + (T.H.H. \times 0.33) + (T.Ec. \times 0.33),$$

where *T.En.* is the total impact of environmental categories, *T.H.H.* the total impact of human health categories and *T.Ec.* the total impact of economic categories.

As previously reported, the most impacting substrate is the perlite, followed by rock wool and vermiculite. The most sustainable ones, instead, are sand and bark (Von Falkenstein *et al.*, 2010) (Figure 2).

From the LCI and LCIA it was possible to calculate the carbon footprint of each substrate. The carbon footprint is a parameter used to estimate the greenhouse gas emissions caused by a product, a service, an organisation, an event or an individual. It is generally expressed in kilograms of CO_2 equivalent, taking as a reference for all greenhouse gases the effect associated with CO_2, assumed to be equal to 1. According to the Kyoto Protocol, the greenhouse gases that must be considered are carbon dioxide (CO_2), methane

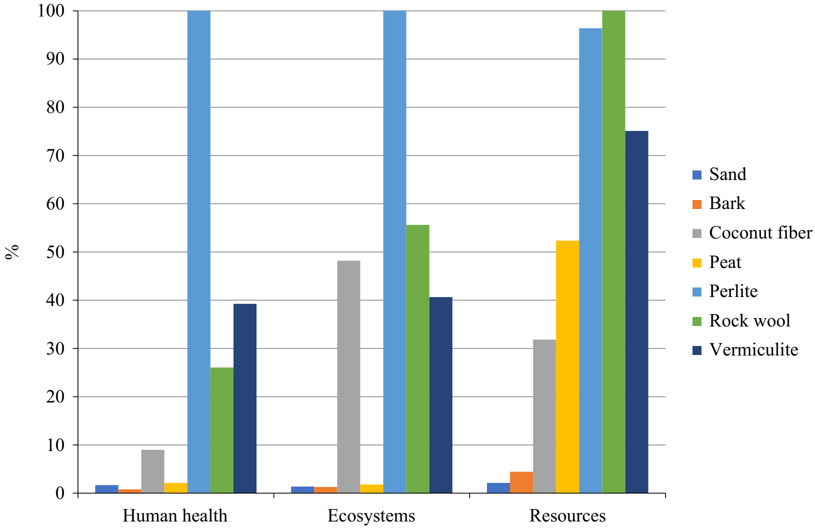

Figure 1.
Substrate life cycle impact analysis for the main impact areas

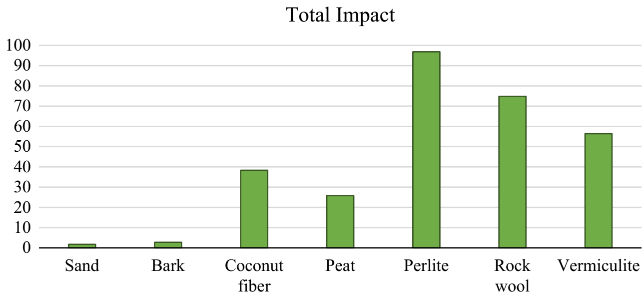

Figure 2.
Substrate life total impact calculated from the impact analysis

(CH_4), nitrous oxide (N_2O), hydrocarbons, hydrofluorocarbons (HFC), chlorofluorocarbons (CFC), hydrochlorofluorocarbons (HCFC), perfluorocarbons (PFC), halon ($CBr_xCl_xF_x$), fluorinated ethers (HFE) and sulphur hexafluoride (SF_6). The substrates carbon footprints were calculated according to Forster *et al.* (2007) as follows:

$$\text{Carbon footprint} = \sum G.G._i \times k_i,$$

where $G.G._i$ is the greenhouse gas quantity produced and k_i is the CO_2 equivalents coefficient for that gas.

This parameter can be used to determine the environmental impacts that anthropogenic origin emissions have on climate changes. According to our calculation sand appears as the substrate with lower carbon footprint, these data are in according to the total impact analysis. The bark carbon footprint results as one of the highest, while in the total impact analysis this substrate seems to be highly sustainable. Also for perlite the two results are in disagreement, it has high total impact but very low carbon footprint compared to the others substrates (Maalouf *et al.*, 2018) (Table II).

4.4 *Life cycle costing*

In this phase, costs were derived using a cost breakdown structure summarised in Table III. Our data were calculated according to specific and direct investigations and observations of the Italian hydroponic market. We want to demonstrate that each substrate has a different implication on economic and environmental impact. The costs showed are related to 1,000 cm^3. From this economic analysis results that the examined substrates are divided into two price categories. The first one with a price lower than €2.00 in which appear perlite, vermiculite, coconut fibre, bark and sand. rock wool and peat, however, have a price higher than €2.00. Peat results the more expensive of the substrate studied while sand the cheaper one (Auer *et al.*, 2017).

5. Conclusions

Nowadays, hydroponic cultivation represents a highly intensive agricultural production methodology. This technique requires high initial capital investments but, over time, it guarantees rapid returns of resources. Hydroponic agriculture allows a high control of the elements used, such as energy, nutrients and pesticides. This cultivation can guarantee a reduction of waste and resources used, as well as the environmental impact. In this work a comparative study on hydroponic substrates was done. Seven substrates were evaluated: rock wool, perlite, vermiculite, peat, coconut fibres, bark and sand. The impact assessment analysis (LCIA) highlighted the most impacting substrate is the perlite, followed by rock wool and vermiculite. Instead the most sustainable ones are sand and bark. From these results the carbon footprint was also calculated. Sand has a lower carbon footprint (0.0121 kg CO_2 eq.) according to the total impact analysis. The bark carbon footprint results as one of the highest (1.1197 kg CO_2 eq.), while in the total impact analysis this substrate seems to be highly sustainable. Also for perlite the two results are in disagreement, it has a high total impact but very low carbon footprint (0.0209 kg CO_2 eq.) compared to the other substrates. From the LCC analysis appear that peat is the most expensive substrate (€6.67/1,000 cm^3), while sand the cheaper one (€0.26/1,000 cm^3). This analysis results that sand can be the best substrate to be involved in hydroponic systems by considering its costs

Substrates	kg CO_2 eq.
Rock wool	0.5620
Perlite	0.0209
Vermiculite	0.2253
Peat	0.0236
Coconut fibre	1.4334
Bark	1.1197
Sand	0.0121

Table II. Carbon footprint of the substrates

Substrates	Cost (€)
Rock wool	2.81
Perlite	0.62
Vermiculite	1.00
Peat	6.67
Coconut fibre	0.50
Bark	1.70
Sand	0.26

Note: All the prices are expressed in € and represent 1,000 cm^3 of substrate

Table III. Life cycle costing (LCC) of the seven substrates studied: rock wool, perlite, vermiculite, peat, coconut fibre, bark and sand

and its sustainability. Therefore, the economic and environmental evaluation of substrates can be a useful and significant tool for the farmer. The substrate influences the crops to choose, the density production and the irrigation system. All these characteristics are burden on the type of production, on the industry typology, on the customers' portion and above all on the costs. So, the in-depth study herein proposed could be used as a valid managerial tool. In addition, the farm can achieve less environmental and economic impacts by choosing a sustainable substrate, also by re-using waste material. Moreover, the evaluation of the substrate sustainability could be used by a legislator in order to regulate and to promote the hydroponic cultivation with specific substrates. This study is limited to the substrate choice, but this research could be a starting point to highlight the best matching of all the inputs, such as raw material or energy used, for the hydroponic production process.

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Corresponding author
Giuliana Vinci can be contacted at: giuliana.vinci@uniroma1.it