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Title: **Ecoinnovation in garden irrigation tools and carbon footprint assessment**

Running title: Smart-gardening-device carbon footprint

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**ABSTRACT**

This article describes the eco-innovative characteristics implemented in electronic devices for irrigation with smart-gardening solutions, such as internet connection for weather forecast and sensors of soil moisture contents, as well as a database with different plants necessities. The main function of these products is to collect and analyse the information related to plants needs, thus reducing water and fertiliser consumption.

In addition to quantify the environmental impact of savings in these two resource flows (40% water and 20% fertilizers savings) compared with conventional irrigation systems, an ISO 14067 compliant life cycle based Carbon Footprint evaluation has been performed to quantify environmental impact of the product itself. The main methodological issue is finding a means on how to proceed when the main environmental benefit of the product under study is, in fact, the service it provides to other systems and when this service cannot be included directly in the

product's carbon footprint calculation due to lack of defined standard-use conditions (such as meteorology or soil composition).

Implementation of smart irrigation tools in gardening and agriculture can lead the transition towards more sustainable production systems worldwide, as well as being an example of business transformation towards resource efficiency improvements through the use of information technology systems to contribute to circular economy.

## **1. Introduction**

Water-energy-greenhouse gases nexus are internationally recognized (Nair et al., 2014) as water availability is crucial for energy production (ie. technologies such as nuclear, thermoelectric and hydropower demand vast amounts of water) and unlimited energy supply would solve water scarcity by desalinization. Nevertheless, this problem is not yet solved nowadays. Agricultural systems are needed for food supply and they are directly associated with water consumption (Gheewala et al., 2017) and with climate change impact (Yodkhum et al., 2017). The most commonly assessed is the contribution of the agricultural activities to climate change due to the emissions of greenhouse gases (GHG). In 2010, GHG emissions from agriculture were estimated to be about 10-12% of the total global anthropogenic emissions (IPCC, 2014). Agriculture contributes to non-CO<sub>2</sub> GHG emissions due to fertilizer application (among other causes), which produces the partial release of its nitrogen content in the form of N<sub>2</sub>O gas (a major contributor to climate change) (Ha et al., 2015; Quirós et al., 2015).

Life Cycle Assessment (LCA) is a very useful and common tool to evaluate the environmental impact when a holistic approach is needed, such as in agriculture systems (Boone et al., 2016). LCA gives a global view of the system studied. Many impact categories are assessed thus preventing burdens transfer (among impact categories, among regions, among sites, etc.), as stated in (ISO 14044:2006). There are other methodologies assessing a single impact category or calculating a single indicator. The most extended indicator nowadays to evaluate a single impact category is the Carbon Footprint (Rebolledo-Leiva et al., 2016), which follows the life cycle approach and has its own standards (ISO 14067 or PAS 2050 for product carbon footprint and ISO 14064 for corporate carbon footprint). More recently the Water Footprint indicator appeared (introduced by Hoekstra et al., 2002) to assess the contribution of a system to water scarcity impact (García Morillo et al., 2015; Lovarelli et al., 2016). It is very important to evaluate and reduce the Carbon Footprint of agricultural systems, mainly because of repercussion of climate change in harvest yields and in the incomes that the farmers will obtain (Soode-Schimonsky et al., 2017). There are multi-dimensional problems surrounding the agricultural sector and they have been increasing during the last few years by the unpredictable and sudden changes in the climate (Bobojonov et al., 2016).

Having agricultural systems great influence to water scarcity (expansion of agriculture significantly affects freshwater resource availability), mitigation strategies and a conscious use are key concerns within this sector. The kind of irrigation system has a very important role in the consumption of water in agriculture and in all their associated impacts, also in the costs (Langarita et al., 2016). Consequently, efficient irrigation systems are needed to support sustainable intensification of agriculture by balancing water use, GHG emissions and food production (Shen and Lin, 2017). It is known that replacing surface irrigation systems with

more efficient pressurized (sprinklers and drip) systems would improve water use efficiency although increasing energy consumption and investment required (Tarjuelo, et al., 2015).

Further steps have been made more recently by developing tools and/or models (using information technologies) to improve the use of water and energy in irrigation. An example is an irrigation scheduling tool for cotton which operates on a smartphone platform (Vellidis et al., 2016). Another example is a satellite-based irrigation advisory system based on dedicated web-GIS (Geographic Information Systems Resource) for farmers and district managers, in three different agricultural systems and environments: Southern Italy, Austria and Southern Australia (Vuoloa et al., 2015). There is also, an irrigation scheduling system that uses the intervention of Geomatic tools that compute the three main parameters influencing the irrigation scheduling namely, crop coefficient, albedo and crop surface temperature through intervention of remote sensing (Kumar Singh et al., 2016).

Although some irrigation systems (ie. flood and drip irrigation) have been assessed through LCA methodology (Yesenia, 2009; Guiso et al., 2015; Eranki et al., 2017), no LCA or carbon footprint or water footprint evaluations have been found up to now of any electronic device helping to reduce water consumption in irrigation.

In Europe, a new economic paradigm is being promoted, named Circular Economy (Ellen MacArthur Foundation, 2012), aimed at creating new business models, at rethinking the products and services and at closing the loop by maintaining the resources as much time as possible in the economic system by recycling and reusing the waste into new products. Within this new paradigm, electronic devices are very interesting, because they can help to redesign products and services, but in addition they need further research to increase their recycling at the end of their life (the recycling rate of small electric and electronic waste is very low, less than 15% according to Eurostat, 2013).

According to the literature (Scharnhorst, 2008), there is an increasing awareness in the electronic-telecommunication industry of the environmental effects related to both the operation and the production of their products as well as of their end-of-life. The need for a life cycle approach is essential.

In the present project, Fliwer-smart gardening system (Fliwer), developed by Involve Newtech S.L, is analysed. The main function of this system is to collect and analyse the necessary information to know what the crops or plants need (fertilizer, water, etc.), when do they need it and the right amount to be dispensed. Fliwer system is compatible with drip and sprinkler irrigation systems.

The main aim of this paper is to describe the innovations implemented to this irrigation tool and to evaluate the Carbon Footprint of this product, as well as, to estimate the savings of water and fertilizers that it reaches compared to a traditional irrigation system. A methodological discussion about the reasons why the Carbon Footprint of the product, following the ISO 14067, doesn't include the environmental advantages of its use (like water or fertiliser savings) will also be included. Finally, a brief discussion of barriers to jump for a wider implementation of this type of tools will be included. Research was carried out in Catalonia from August 2015 to May 2017.

## 2. Materials and methods

### 2.1. The eco-innovative irrigation tool

#### 2.1.1. Product description

This study analyses the production system to obtain a unit of the smart-gardening tool. This tool enables savings in water consumption, since the plants are watered only when the sensors detect that the soil is insufficiently moist; in this way, this tool is saving a lot of unnecessary irrigations that are made nowadays with irrigation clocks that do not consider any factor. In addition, the smart-gardening tool connects to meteorological services and consults the probability of rain before watering, if this probability is very high, it will hopes for rain. If this forecast is met, it will generate water savings and will avoid water stress to the plant. It also checks the weather to avoid watering when there are strong wind conditions if watering is spraying, and warn of possible adverse agents like hail.

The smart-gardening tool also allows the anticipation of problems and plant diseases, such as warning about fungus when the plant is exposed to characteristic moisture, temperature and light. It is also connected to the pest information institutes that warn about the onset of parasites, so the consumer can react in time.

The specific product evaluated here, Fliwer, is composed by three components: Fliwer sensor, Fliwer control of 24V or 9V and Fliwer link wifi or 3G (see Fig 1). The system includes the analysis upstream and downstream of all the elements necessary to obtain this product.



**Fig 1.** Components of Fliwer-Smart Gardening system (Source: Involve Newtech, 2017)

The first component is the sensor, this device is positioned next to the plant or group of plants that the consumer wants to care for, and its function is to monitor the vital parameters of the plant and its environment through its intelligent sensors. There is no optimal or general number of soil-sensors needed to adequately represent the spatial variability of soil-water distribution,

because this distribution depends on the space heterogeneity (soil type, slope, soil compaction, orientation, shadow, etc.) and plant biodiversity. For example, a grass football field of 5000 m<sup>2</sup> can be controlled with a unique sensor, while if we talk about a garden with different types of soil, sun and shadow areas, aromatic plants, flowers or grass, one sensor would be needed for each differential area. The more correct would be to say that a sensor is needed for each differential area of your garden, understanding area as a homogeneous unit with the same type of soil, slope, shadow, plant-type or irrigation system. The home sensor scans the first 20 cm depth. In the case of a professional version, the sensor has a cable that can be placed at any depth. It must be said that most plants have its most important part, representative of the root, at the first cm of depth; especially the grass which is the star plant for the studied sensor and the one that provides greater savings.

This device incorporates a low consumption system, since it is powered by high performance lithium batteries which allow great autonomy, having to charge them only once a year. In addition, the sensor is ready to resist all adverse agents found during its lifetime, thanks to the covers made of ABS (acrylonitrile butadiene styrene), a plastic material resistant to the effects of weather (sun, heat, cold, wind, water, soil moisture, etc.). Furthermore, it is welded using vibration technology to ensure a well seal. Finally, Fliwer sensor does not use wires and does not imply any installation process or any adaptation of the garden.

Fliwer Sensor monitors the state of plant life through:

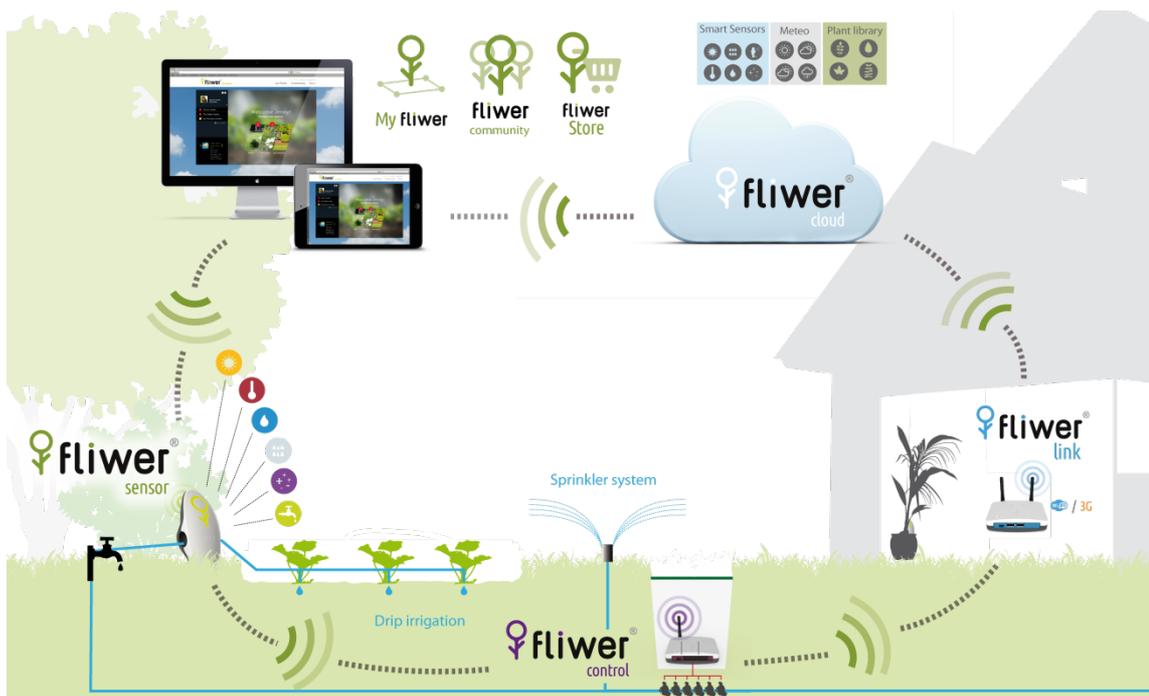
- Light sensor: checking the level of light that receives the plant and controlling the photoperiod.
- Temperature sensor: checking if the temperature of the plant is correct and acting preventively against frost.
- Air humidity sensor: detecting the air humidity and sending an alert if it is not adequate.
- Soil humidity sensor: activating irrigation only if the water content has reached the necessity level.
- Electro-conductivity sensor: controls the conductivity to decide when to fertilize and the right fertilizer amount.
- The integrated solenoid-valve: autonomous irrigation system through the valve integrated in the sensor.

The second component is the Fliwer Control, a device positioned as a central irrigation control and totally compatible with irrigation systems and valves of the market. This component does not need to be programmed, since it only allows watering when the plant needs it and the weather forecast recommends it. Control function consists on activating and/or shutting down the irrigation based on the information collected by Fliwer sensors. There are two types of Fliwer Control; the first one is called Fliwer Control 24V operated with valves DC (24V), which must be connected to the electricity grid using a power adapter. The second type is the Fliwer Control 9V operated with pulse solenoid (9V), which must be connected to a battery pack; this second model is used in locations without access to the electricity grid. The most common model, Fliwer Control 24V, is the one studied in the present project.

The third component is the Fliwer Link, a device that enables communication between sensor and online platforms. Fliwer Link is able to communicate through wireless

connection to the closest sensor. The scope between them is about 100 meters with direct vision. This device connects to the Internet via WiFi or 3G (mobile network). The link device works as charging station of sensor devices through a USB connection. While the sensor is charging, the link device is performing a maintenance and verification service of the sensor device. The most common model, Fliwer Link Wifi, is studied here.

All devices that form the Fliwer system communicate each other using radio frequency (RF), forming a smart mesh network (smart grid). It is a system that allows efficient communication and at the same time, large energy savings.



**Fig 2.** Operation of Fliwer-Smart Gardening system (Source: Involve Newtech, 2017)

### 2.1.2.-Software included in the product

Fliwer’s software is a system based on the “Internet of Things” and smart devices. For this reason, firmware (a type of software that provides low-level control in direct interaction with the hardware) is developed, with the basis of this concept, using wireless networks. Firmware includes an operating system in real time, a protocol of synchronization and communication between devices that makes the system communicate effectively and efficiently. The operating system allows managing all the tasks that each device must execute sequentially and orderly. Each of the tasks that the device must develop is organized in execution events that are triggered when a certain priority arrives. Furthermore, algorithms have been applied in the firmware that allow putting parts of the device in very low consumption state when it is necessary, generating a greater autonomy of the devices fed with battery and greater energetic efficiency in general. Also, through the algorithms, calibration curves have been performed for each sensor, thus avoiding deviations in the parameters analysed by the sensors.

In order to correctly generate the best possible irrigation configuration, a proper algorithm has been applied to place correctly the actuators of each irrigation-related valve in the zone (area of the garden or crop), so that it meets the requirements of simultaneity and at the same time is the fastest way.

The most important innovation aspect is the part of the server used as decision engine and event engine, since unlike known irrigation programmers, Fliwer system allows both irrigation programmed by the user and irrigation by necessity, being the last one conditioned by other factors of the environment (ie., adequate ambient temperature, wind or rain probability).

At the user level, a user can configure the events of a zone in the irrigation area through the task manager, where the user can mark what times of the day are allowed automatic events or block the generation of irrigations for a few hours either once, daily, weekly, monthly or annually, just as the user can force an event in those time periods.

### *2.1.3. Fliwer-Smart Gardening compared to other described irrigation tools*

Nowadays many irrigation systems are developed. In the introduction some different irrigation tools that share some features with Fliwer system are mentioned. One of them is a smartphone application for scheduling in cotton fields that uses meteorological data from weather station networks, soil parameters, crop phenology, crop coefficients, and irrigation applications to estimate root-zone-soil water deficits (RZSWD) in terms of percentage as well as of inches of water. The cotton app sends notifications to the user when the RZSWD exceeds 40%, when phenological changes occur, and when rain is recorded at the nearest weather station (Vellidis et al., 2016). Another irrigation tool that share some characteristics with Fliwer system is a satellite-based irrigation advisory system based on dedicated Geographic Information Systems (webGIS) or farmers and district managers, applied in three different agricultural systems and environments: Southern Italy, Austria and Southern Australia. The key-point of the procedure of this tool is a personalised irrigation advice and timely delivery of the information (Vuoloa et al., 2015). Likewise, in the introduction it is mentioned an irrigation scheduling using remote sensing and GIS based in the computation of the three main parameters that influence the irrigation scheduling: (i) crop coefficient; (ii) albedo (measure for reflectance or optical brightness) and (iii) crop surface temperature (Kumar Singh et al., 2016). Although these three described irrigation systems are not directly comparable, since they address different context and users (ie. satellite system addresses spatial scales from the farm to the district or regional levels, which are not affordable with ground-based sensors), the authors wanted to describe them to show what can be found in the literature and to stress the originality of the system studied in the present paper.

In addition, in the Spanish context, few different smart-tools are in the market, but they cover only a small part of the functionalities covered by the one studied here. The main difference between these irrigation systems and the present one is that they do not use ground-based sensors. They don't use weather forecast or artificial intelligence as a decision tool and they don't have a library of plants or a virtual community with contact to customers and suppliers and access to information from the governmental agriculture department.

## *2.2. Carbon footprint methodology*

There are two main standards that describe how to perform a product carbon footprint (PCF): the British standard PAS 2050:2011 and the International standard ISO 14067.

The referential PAS 2050:2011 (Publicly Available Specification) has been developed by the British Standards Institution, in response to requirements from industry, with the goal to have a consistent method to assess the emissions of greenhouse gases along the life cycle of goods and services. The use of PAS 2050 helps to make a reliable assessment of the emissions associated to goods and services in their life cycle following the methodology of Life Cycle Assessment (LCA) described in the standards ISO 14040 and ISO 14044. The use of the PAS 2050:

- Allows the evaluation of current emissions of greenhouse gases during the life cycle of goods and services.
- Provides a common basis for better understanding by consumers of the emissions of greenhouse gases in the life cycle in order to take decisions about the acquisition and use of certain products.

The recommendations and requirements of the methodology from the British Standards Institution (BSI) PAS 2050:2011 were used in the development of ISO 14067. Thus, this international standard was inspired by the previous PAS 2050 standard. This methodology establishes standards for the calculation and assessment of the carbon footprint during all life cycle of the product from extraction of raw materials, product production and distribution, until it reaches the final consumer use and end-of-life. ISO 14067 methodology was followed in the present study.

Carbon footprint assessment may have two different scopes, from “cradle to grave” or from “cradle to gate”, according to ISO 14040. First approach includes all environmental burdens from the extraction of raw materials, production and distribution of the product, use and maintenance and end-of-life, while the second approach only includes from raw materials until product production and packaging to the gate of the production site. In the present study, first approach will be taken, named “business to consumer” in PAS 2050 standard.

### *2.3. Scope of the study and system boundaries*

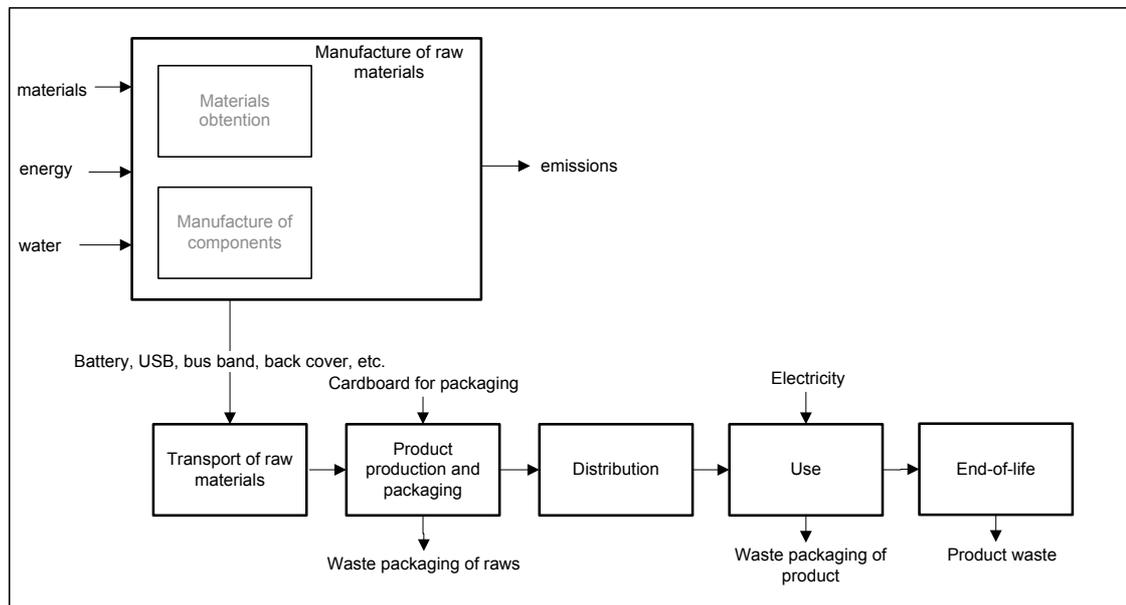
The aim of the present carbon footprint study (PCF) is to evaluate the environmental impact of smart-gardening product to know the main hotspots and to find ecodesign options, if possible.

As mentioned above, the calculation of the carbon footprint should be done taking into account the entire life cycle of the product, which is called in the ISO 14040 “cradle to grave” and in the referential PAS 2050 is defined as “business to consumer”.

The life cycle stages analysed in the present study are shown in Fig 3:

- Manufacture of raw materials: It includes the manufacture of all raw materials used.
- Transport of raw materials: It is the transport of raw materials to the plant. It also includes the manufacture of its packaging.
- Production and packaging of the system: It includes all manufacturing stages carried out at the production plant. It also includes the management of waste generated during the manufacturing, the packaging waste of raw materials and the manufacture of packaging materials used in the finished product.
- Distribution of the product.

- Usage: It means the electricity consumption during the use phase of the product and the percentage of faulty production that it must be replaced.
- End of life: It is the transport and waste management of the product and its packaging at the end of its life.



**Fig 3.** System boundaries

The functional unit of the study is defined as "one Fliwer system consisting of a sensor, a 24V control device and a wireless device Fliwer-link-wifi, with a service for one year".

The company believes that the system Fliwer, if used correctly, has an indefinite useful life time without the need for maintenance or replacement of components. The only way to assess the impacts per year is by putting a defined life time which has been established in 10 years. Thus, the impacts of the product production have been distributed among all these years and the values presented here represent the annual environmental impacts.

The main hypotheses of the study are the following:

- Spanish electricity grid mix was considered, being the product manufactured in Spain.
- In the case of transport by truck, the following assumptions were made: the truck always goes 85 % full of its capacity, the driving is in both dual carriageway and urban, it has only been assigned the outward journey, because it has been alleged that in the return journey the truck is transporting some other product.
- For the raw materials: generic manufacturing process for all components (batteries, internal circuit boards, USB cables, etc.) was used. For the manufacturing process of the sensor charger (5V), due to lack of more appropriate data, a proxy has been used, assimilating it with the manufacture of an USB, excepting that the weight was doubled.
- In the management of waste generated: for waste resulting from packaging of raw materials and packaging of the product, recycling was considered as the only option. For end-of-life of Fliwer devices 11.9% recycling and 88.1% landfilling was considered being these percentages the average values for small electric and electronic waste (WEE) recycling and landfilling in Spain in 2013 (Eurostat, 2013). The distance for the transport of waste to the different treatment plants was considered 40 km.

- To describe the distribution of Fliwer, Involve Newtech estimated that 10% of production is regionally distributed in Catalonia, 80% is marketed and distributed in Spain, 7% in Milan (Italy) and the remaining 3% in the rest of the world.

The impact indicator used is Global Warming Potential (excluding biogenic carbon) with a time horizon of 100 years.

### 3. Results and Discussion

#### 3.1. Inventory data for Fliwer-Smart Gardening system

This stage includes the inputs and outputs of Fliwer life cycle: raw materials manufacturing, packaging and transport of raw materials, production and packaging of the product, distribution, usage and end of life management.

Inventory data used is foreground, obtained from direct measurements, for raw materials and packaging (ie. weight of components and type of material) and background data from Thinkstep and Ecoinvent databases was used for the production processes of electricity, transport and manufacturing of components. Geographical area of the data is Spain whenever possible and European average (if no data for Spain was available). Time period representativeness of the background data was 2016-2019.

The inventory data below (Tables 1 and 2) correspond to a Fliwer system (made up of three devices), which is considered to have a useful life of 10 years. Electricity consumption in the use phase is presented corresponding to only one year. Table 1 also shows the distribution of the product.

In order to meet with the defined Functional Unit, impacts of manufacturing have to be distributed among its 10 years life, so the results of the carbon footprint of the system correspond to the impact of one of those years.

Table 1. Inventory data for Fliwer system: components of the product and their origin.

INPUTS		Origin	Distance	INPUTS		Origin	Distance		
Raw materials	g	country	km	Raw materials	g	country	km		
Fliwer Sensor	Frontal case	73	Spain	Fliwer Link	Rear case	31	Spain	146	
	Leds PCB	5	Spain		96	Link wifi PCB	22	Spain	96
						Frontal case	2	Spain	146
	Rear case	88	Spain		146	Antenna	16	China	16346.69
	Power MCU antenna PCB	12	Spain		96	Upper case	29	Spain	146
				Sensor		8	Spain	9	Fliwer control
					Control 24	24	Spain	96	

	PCB					PCB			
	Electrovalve	144	China	16346.69		Frontal case	2	Spain	146
	Gasket	4	Spain	146		Antenna	8	China	16346.69
	Bus band 8P	0.2	China	16346.69		Upper case	29	Spain	146
	Bus band 10P	0.2	China	16346.69	Fliwer Sensor	Charger	5	China	16346.69
	Battery	46	China	16346.69		Cable USB	2.5	China	16346.69
	Back cover band	4	Spain	146		Female-female connector	4	China	16346.69
	Laterals bands	4	Spain	146		Female fast connector	4	China	16346.69

Table 2. Inventory data of Fliwer system: other data

Life cycle phase	INPUT	Mass (g)	Distance (km)	OUTPUT	Mass (g)	Distance (km)
<b>Assembling and packaging</b>	Cardboard packaging of Fliwer	387	0	Weight packed product (to distribution)	984.9	
	Components from Table 1		-	Waste packaging raw materials (cardboard)	71.3	40
<b>Distribution</b>		Mass (g)	Destiny	Distance (km)	Type of transport	Comments
	Packed product	984.9	Spain	671.8	truck	80% Spain
			Catalonia	16.4	truck	10% Catalonia
			Italy	107.5	truck	7% Italy
				737.5	plane	
Rest of the world	107.5	truck	3% rest of the world			
	6487.3	plane				
<b>Use phase</b>	INPUT			OUTPUT		
	Electricity consumption (kWh/year)	43.81		Defective product (g)	5.98	
	Components for maintenance (g)	5.98				
<b>End-of-life</b>	OUTPUTS		Treatment distance	Type of tretment		
	Type of waste	g	km	11.9% recycling and 88.1% landfilling		
	Fliwer waste (plastic)	473.4	40			
	Fliwer waste (metal)	124.5	40			
	Fliwer packaging waste (cardboard)	387	40			

### 3.2. Average carbon footprint results

This study considered two scenarios:

- i. Scenario 1: The user consumes electricity from the national standard electricity mix in Spain to charge and plug Fliwer system.
- ii. Scenario 2: The user consumes electricity from an electricity mix 100% from renewable sources to charge and plug Fliwer system.

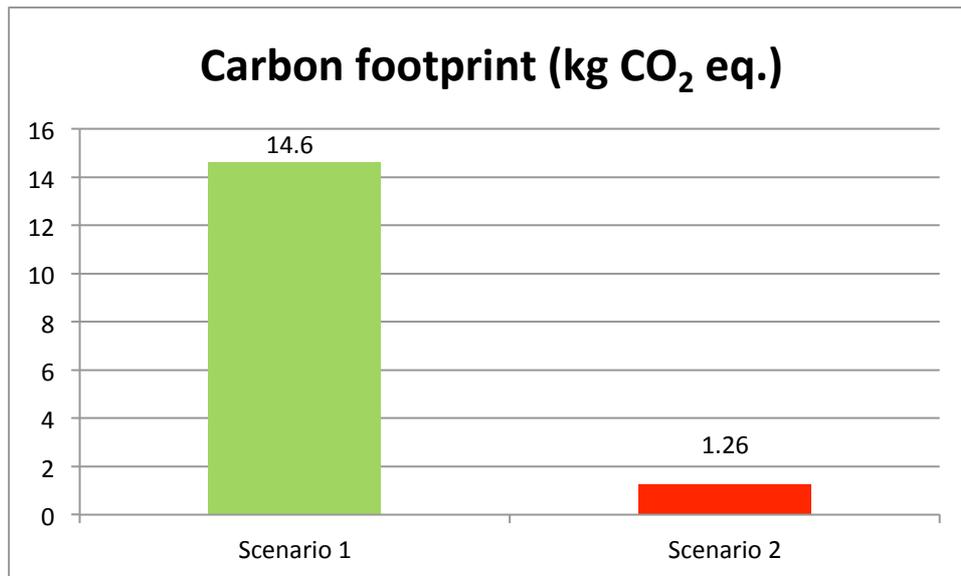
The results of the carbon footprint of the product show (see Table 3) that the most contributing aspects depend on the scenario considered:

- i. Scenario 1: The use phase is the one that contributes the most (91.6%) in the final carbon footprint result.
- ii. Scenario 2: The raw materials manufacturing phase is the one that contributes the most (86.3%) in the final result.

It has to be noted that the use of an electricity grid mix or other is competence of the final user of the product, not the production company. Indeed if the consumer use 100% renewable electricity, the carbon footprint is reduced by 91.1% compared with the consumption of standard Spanish electricity grid mix (see Fig 4). A suggestion on the type of electricity to be used by the consumer and its effects should be included in the product.

**Table 3.** Fliwer-Smart Gardening system carbon footprint results

	Raw materials manufacturing	Raw materials packaging and transport	Production and packaging	Distribution	Use	End of life management	TOTAL annual
<b>Scenario 1 (kg CO<sub>2</sub> eq.)</b>	1.17E+00	2.09E-03	3.21E-02	1.78E-02	1.33E+01	3.86E-03	<b>1.46E+01</b>
<b>%</b>	8.01	0.01	0.22	0.12	91.6	0.03	100
<b>Scenario 2 (kg CO<sub>2</sub> eq.)</b>	1.17E+00	2.09E-03	3.21E-02	1.78E-02	1.17E-01	3.86E-03	<b>1.26E+00</b>
<b>%</b>	86.3	0.17	2.54	1.41	9.25	0.31	100



**Fig 4.** Fliwer-Smart Gardening system carbon footprint results

### 3.3. Recommendations for process improvement

Some eco-innovation actions that can be implemented to improve the environmental profile of the studied smart-gardening system and to reduce the carbon footprint are suggested. One of the most important options to reduce the carbon footprint of the product would be mainly related with the energy consumption in the use phase. The product could include a suggestion to consumers to use an electricity mix from renewable energy sources. The use of 100% renewable energy sources would mean a decrease of 91.1% of the carbon footprint related to the use of the average Spanish grid mix. Another option would be a further development of the product design to include solar cells (ie. flexible organic photovoltaic cells) in the devices so that they would not need to be connected to the grid.

Other additional (less contributing) recommendations would be: the use of recycled plastic materials for the ABS housings (which would reduce the carbon footprint of the product about 0.5%) or trying to find other additional features (multifunction of the product, like connecting the system with home automation that allows to close the blinds when there is a high probability of rain), redesign the product to facilitate its recyclability at the end of its useful life or search a Spanish supplier for the raw materials that nowadays are coming from China, among others.

### 3.4. Water and fertilizer savings during the use of Fliwer-Smart Gardening system

Fliwer main innovation is saving water and fertilizer which is possible thanks to the intelligent system that irrigates only if it is necessary. Fertilizer savings are achieved due to less water used (less lixiviation) and due to electro-conductivity sensor (controlling ion concentration in the soil, thus avoiding fertilizer excess and defect). The savings of water and fertilizer were studied during two months in three different zones (private garden, public park and farm) in the region of Catalonia (Spain) (see Table 4). Fliwer is compared to a system with irrigation scheduling, which is the most common nowadays for gardens. The system consists on controlling irrigation by defining its duration and frequency. In Catalonia, most gardeners program one irrigation per

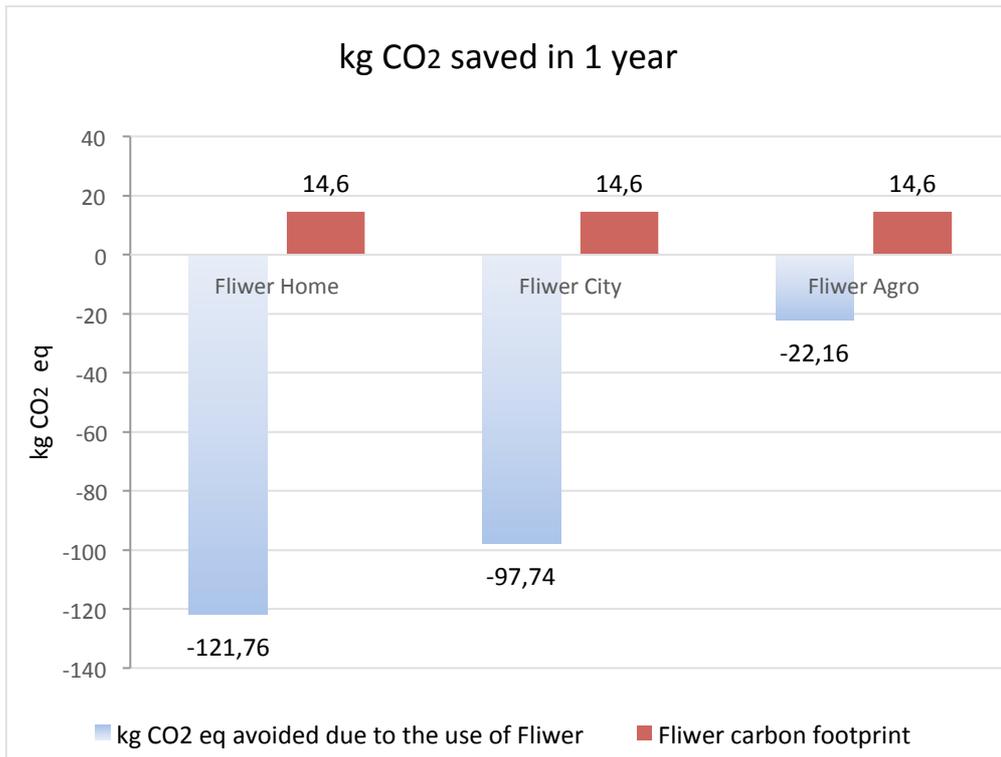
day, with sufficient duration to reach about 4-6 L per square meter of grass (duration depends on the type of sprinkler: the more water it pulls, less time is needed to apply the desired dose). The comparison was performed by recording the water spent in a garden with Fliwer compared to the amount that would have been spent in the same garden with the previous programmed system. That is, to calculate the amount of water that would have been used with the previous system, in the same garden and time-period, We just need to know how many litres were spent on one day of irrigation and multiply by the number of irrigation days in this period (watering was previously done every day the same).

After extrapolating to one year the saves achieved in two months, the results of the carbon footprint presented in Fig 5 are obtained. It shows the CO<sub>2</sub> eq emission savings due to the reduction in water and fertilizer consumption (e.g. 73.1 m<sup>3</sup> water and 11 kg fertilizer saved by Fliwer home in 2 months). In the three cases (Fliwer home, city and agro), the savings in kg CO<sub>2</sub> equivalent are higher than the emissions for the product manufacturing.

**Table 4.** Experiments done to evaluate savings due to Fliwer-Smart Gardening system

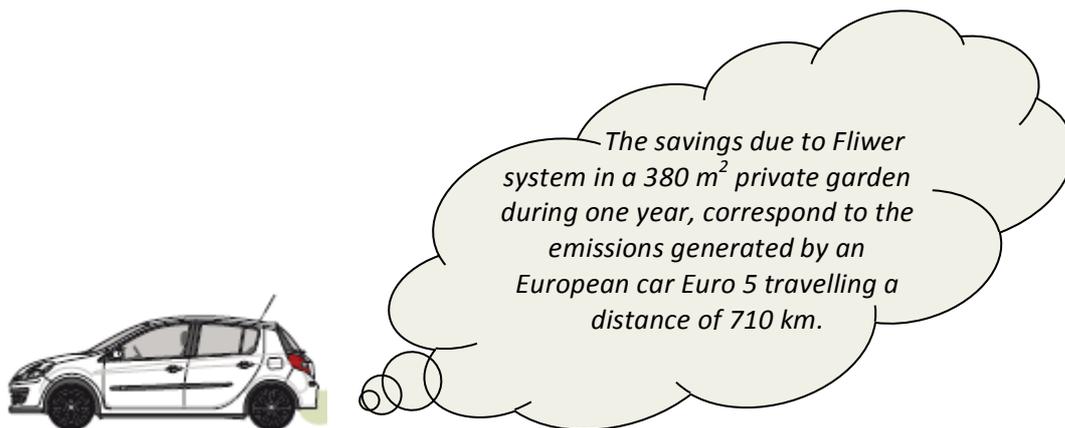
Aspects	Fliwer home	Fliwer city	Fliwer agro
<b>Studied period</b>	01/05/2016 to 30/06/2016	01/08/2015 to 30/09/2015	04/07/2016 to 04/08/2016
<b>Area (m<sup>2</sup>)</b>	380	3600	37000
<b>Fliwer devices installed</b>	1 control, 1 sensor, 1 link	2 controls, 2 sensors, 1 link	2 controls, 6 sensors, 1 link
<b>TOTAL saved irrigations* (n°)</b>	44 (link 8, sensor 36)	22 (link 10, sensor 12)	
<b>% saved water (%)</b>	73	37	25
<b>Fliwer irrigations (n°)</b>	16	38	59
<b>Irrigations done by the previous system (n°)</b>	60	60	59
<b>water consumption with Fliwer (m<sup>3</sup>)</b>	26.6	820.8	5806.6
<b>water consumption with the previous system (m<sup>3</sup>)</b>	99.7	1296	7258.2
<b>Saved water (m<sup>3</sup>)</b>	73.1	475.2	1451.6
<b>Saved fertilizations (n°)</b>	1	1	
<b>Saved fertilizer (kg)</b>	11	108	148 (20%)

\*It includes the savings from link and sensor.



**Fig 5.** Water and fertilizer savings during the use of Fliwer-Smart Gardening system

The savings due to the use of the smart-gardening solution in a private garden of 380 m<sup>2</sup> during one year correspond to emissions generated by Euro 5 European car that crosses a distance of 710 km. (see Fig 6).



**Fig 6.** Savings due to the use of Fliwer-Smart Gardening system

### 3.5. Product Carbon Footprint: methodological discussion

A Product Carbon Footprint (PCF) is, according to ISO 14067, the quantification and communication of GHG emissions and removals during the life cycle of a product or a service.

In the present study the product studied was a smart irrigation system composed by three devices (sensor, link and control). The service offered by this product is to maintain the plants cultivated in a specific area correctly irrigated and fertilized.

The company producing Fliwer was interested in showing the benefits of the product, water and fertilizer savings due to its use, but these benefits were not directly shown with the PCF calculation and communication. Why? Because the carbon footprint study was analyzing the product and not the service provided. The difference between analyzing the product or analyzing the provided service affects to the functional unit that needed to be defined (the unit to which all data will be referred to).

If we want to analyze the product, a physical type of functional unit could be defined, like the one defined here: "one Fliwer system consisting of a sensor, a 24V control device and a wireless device Fliwer-link-wifi, with a service for one year".

If it is the service what we want to analyze, a functional type of unit should be defined, like for example: "1 year of irrigation service for 1 m<sup>2</sup> of land located in an area and cultivated with a specific type of plant" or "the irrigation needed to have a harvest of x tonnes of a specific plant in a specific area". These types of functional unit are the ones needed for comparisons, because what we should compare are products providing equivalent functions. When performing comparisons, special care is needed to make the calculations with equivalent product category rules, hypothesis, quality of data, etc. In this case, to compare Fliwer with a conventional irrigation system, data has to be collected from experiments performed in the same conditions (type of land, weather, type of plants, etc.).

So, why not analyzing the service provided by Fliwer, if the company wanted to show the benefits of its use? Because no standard use conditions are defined for this product. Instead, there are other products for which standard use conditions are defined, thus allowing to evaluate the service they provide. For example in the case of cars, the fuel savings during the use of a car can be evaluated in standard well defined conditions. Another example is the use of a detergent, which can produce water or energy savings (because it is able to wash at lower temperatures). Also standard and general washing conditions can be defined. Therefore, the service provided by these products (ie., cars and detergents) can be well evaluated by defining the appropriate functional unit (ie., "100 km travelled with the car" or "amount of detergent needed to wash 1 kg of clothes in a common industrial washing machine").

Nevertheless, in those case studies like the present one, for which no service can be evaluated due to lack of standard use conditions, an additional and separate module can be included, quantifying the environmental savings due to the use of the product. This is the same solution adopted by the construction sector in materials and products like insulation to quantify the energy savings during the use phase of the building, which clearly depend on the weather of the area, the situation of the façade, etc. Thus, according to EN 15804 (standard for construction-products category rules), the energy or water savings in a building during the use phase of this building and due to specific products such as an insulation panel or a water saving device will be separately evaluated in modules B6 and B7 of the standard, respectively. In this same standard, building life cycle is classified in 4 stages (see Fig 7): product stage (A1-3), where all products needed in the building are produced; building construction (A4-5); use of the building (B1-7) and end of life stage (C1-4). The energy savings achieved by a specific type of insulation will be different depending on the building location (ie. Montreal vs Barcelona), due to climate

differences during the same year. Therefore, if the calculation of B6 is included in the environmental product declaration (EPD) of the insulation product, it will be included separately and the conditions considered for this calculation will be stated.

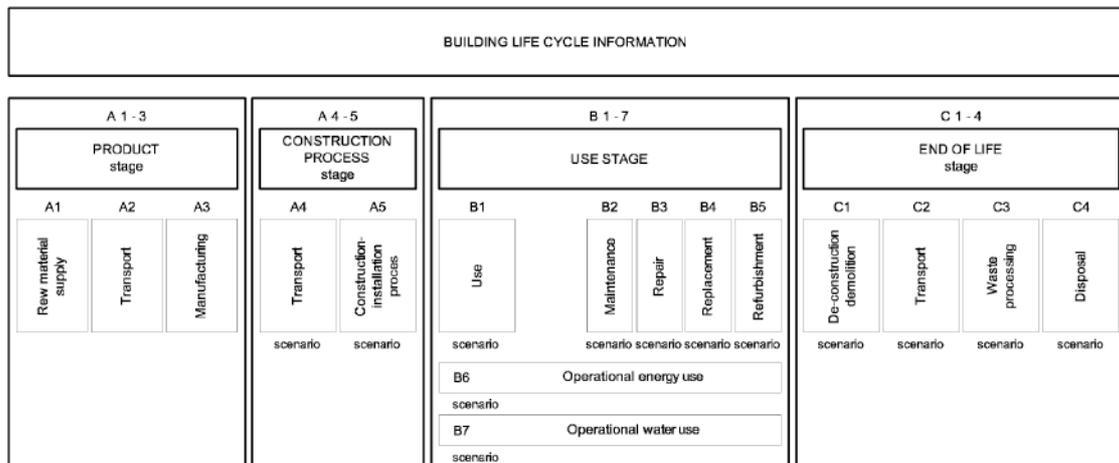


Fig 7. Life cycle stages of a building which can be included in an EPD (source: EN 15804: 2012).

Summarizing, companies that want to show the main environmental benefits achieved by the use of their products, when no standard use conditions are defined (due to different reasons), (ie. water and fertilizer savings thanks to Fliwer) should calculate the PCF by evaluating the product (not the service) and include a separate and additional module showing how to calculate the environmental benefits from the use-phase-savings provided. In this way, the users of the product will be able to calculate their specific savings thanks to the use of the product in their case and conditions.

As an example, if we have a garden near Girona (Spain) with an area of 380 m<sup>2</sup> and we install the smart-gardening solution, we will avoid about 439 m<sup>3</sup> of water and 66 kg of fertilizer per year (see Table 3). In this case, we will add 14.6 kg CO<sub>2</sub> eq per year to our garden's emissions due to Fliwer life cycle, but it will reduce them by 121.8 kg CO<sub>2</sub> eq due to water and fertilizer savings in the same year (see Fig 5, Fliwer home). Nevertheless, the annual savings of water and fertilizer of a specific cultivated area will depend on the location and year of the measure.

### 3.6. Key points for worldwide implementation of such innovative irrigation tools

Agriculture is water intensive in general and accounts for 70% of the global freshwater resource (Vörösmarty et al., 2010). Thus, regions of intensive agricultural practices and dense settlement may result in high water risks (Calzadilla et al., 2010). This is the case of China, for example, where major concern is paid to water pollution and water scarcity (Huang et al., 2010). But, when the price is low and not related to the amount of water use, the benefit from water saving is low or nonexistent (Shen and Lin, 2017). As a result, farmers have no incentives to save irrigation water, leading to another problem facing the agricultural water management all over the world (i.e., low efficiency in irrigating water use). Shen and Lin, 2017 conclude that China should achieve the sustainable use of agricultural water mainly through increase in the technical efficiency of agriculture and the spread of water-saving irrigation techniques. The product

presented and evaluated here can contribute to the sustainability of agriculture and gardening systems, although price is still a barrier for its global implementation worldwide.

On the other hand, the work presented here contributes to accurately communicate the contribution of this product to the sustainable use of resources, mainly water, within the agriculture (and gardening) sectors. Rigorous environmental communication contributes to increase the perceived value of the product, which is a key factor for its introduction to the market.

#### **4. Conclusions**

The eco-innovative characteristics implemented in an electronic device for irrigation with smart-gardening solutions, such as sensors of humidity and soil ion-content, as well as internet connections for weather forecast and a database with different plant necessities have been described. This is a case study of new business strategies towards resource productivity improvement that can be implemented worldwide.

Experiments have been performed in the same place and conditions to quantify water and fertilizer savings with and without Fliwer system in three different zones: a home garden, a city park and a farm. Fliwer system is a very good product for the following reasons: it saves water (about 40%) and fertilizer (about 20%) by being a smart irrigation system that irrigates only when is needed (depending on weather conditions, soil moisture and the needs of the plant). Saving fertilizer is given by the least amount of irrigation water used and by the soil ion-content sensor. In addition, it requires little energy use.

In order to calculate the environmental impacts and gains, a product carbon footprint (PCF) has been performed, which has helped to identify weaknesses throughout the life cycle of the product. The results of a single indicator, carbon footprint, although important, are not complete, and for a deeper sustainability study other impact categories would need to be assessed as well as some indicators from the social and economic spheres. However, sometimes a fully fledged LCA is not really needed and “good enough is best” options can be used (Bala et al., 2010). It should be noted that the carbon footprint is not an indicator to display real environmental problems from electrical and electronic waste management, since the GHG emissions are not the main problem of these discharges. In fact, one of the environmental challenges of today’s society is to increase the percentage of recycling of electrical and electronic waste, as currently is very low (Scharnhorst, 2008). Research in this area is needed, following the circular economy policies implemented in Europe, to find new added value products from e-waste.

Fliwer product as a case study has shown how to proceed when both the main environmental benefit of a product comes from the service it provides (during use) and no standard conditions have been defined nor agreed to quantify such a benefit. In this case, together with the PCF calculation, an additional module quantifying the environmental benefits provided by the product in specific using conditions shall be separately included. This communication aspect has great importance to promote and extend business eco-innovation and to help transformation of industry patterns towards a more sustainable use of resources.

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The authors are responsible for the choice and presentation of information contained in this paper as well as for the opinions expressed therein, which are not necessarily those of UNESCO and do not commit this Organization.

## Conflict of interest

The authors declare that they have no conflict of interest.

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