Advantages of clustering

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WP1 Environmental and Economic Assessment

Task 1. 4 Advantages of Clustering

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0. Introduction

This study is part of task 1.4 Advantages of Clustering of the Euphoros Project. It is a prospective study of the possible advantages of clustering different industries in the format of an agricultural-industrial estate in order to meet sustainability goals:

a) Environmental advantages: sharing resources and reusing waste.
b) Social advantages: maintaining activity.
c) Economic efficiency.

In a previous study the economic risks of agroparks have been identified and analysed. (LEI,2011). Such project aimed to develop a generic framework which could be used to quantify the financial and economic risks of agroparks. In order to evaluate agroparks, it is important to assess the formation risk, the organizing costs and impact of different institutional arrangements in the specific context.

The intention of Deliverable 22 was to perform a first assessment from an environmental point of view only; future works are expected to broaden the scope of Deliverable 22 by including the aforementioned financial and economic risks of agroparks. Given the complexity of the topic, we have decided to use a case study as an example. To this end, we have used background information from a previous study carried out in the Canary Islands, where the production sector is very similar to the Mediterranean greenhouse production system in terms of the type of technology used and the characteristics of horticultural production. This deliverable presents the results of establishing synergies between different industries in order to improve energy balance, global warming and water consumption.

During the execution of the project A Comprehensive Vision of Greenhouses and Regions: Synergies for Increasing Environmental and Energy Efficiency (Visión integral invernaderos y territorio: sinergias para una mayor eficiencia medioambiental y energética) (Ref: RTA2008-00109-C03-02), it was discovered that the sales phase for tomatoes has one of the highest impacts in most of the impact categories studied [Torrellas et al., 2008; Antón et al., 2009], mainly due to the type of cardboard boxes use to transport the tomatoes [Claret, 2011]. Some of the conclusions reached in this study to improve the box in environmental terms included using recycled paper to manufacture the corrugated cardboard, producing paper and using cellulose fibre obtained from biomass waste. These conclusions triggered the idea of creating a network of connections between the paper industry, waste-paper management companies and farmers in order to make use of the by-products of one activity as raw materials for the other.

1. Background

Industry is a major consumer of the resources available in the environment. This includes the land where the buildings are located and built, construction materials and energy resources used, the water used in the different industrial process and cooling water, and the machinery [Côte & Cohen-Rosenthal, 1998]. However, natural resources are limited and the cost of accessing them is increasingly more expensive. This is exacerbated in many areas, where the availability of resources is not sufficient to meet the demand of industrial and economic activities, and it becomes necessary to import resources from outside, thereby increasing the economic and environmental costs involved. At the same time, many areas devoted to horticulture also face difficulties with waste management due to their geographic limitations and to a lack of sufficient waste-treatment facilities [Abuyan et al., 2000; PIRCAN, 1999]. In regions with mild climates, these areas may also be major tourist destinations. For example, the Canary Islands received more than 8.5 million tourists in 2010 and has a population of little more than 2 million [ISTAC, 2011]. However, in 2011, the islands generated 1,151,349 tonnes of urban waste and 118,185 tonnes of industrial waste [ISTAC, 2011]. The influx of tourists and the seasonal increase in the population is an important point to take into consideration when planning waste management and treatment systems in the islands.

In this context, improving efficiency in the use of raw materials and recovering industrial and urban waste is an essential step towards providing more sustainable foundations for economic development [Roberts, 2004]. To achieve this, Roberts proposes that the consumption and production methods of systems controlled by humans be designed to mimic the efficiency of natural systems, where organisms produce waste that is turned into new resources in a continuous system of production and consumption. Industrial ecology looks for new uses for emissions and waste material and points to reorganizing industries so that the waste from one industry becomes a resource for another [Frosch and Gallopoulos, 1989].

The industrial counterpart of an ecosystem is the industrial ecopark [Ayres, 2002], which involves applying the principles of industrial ecology to manufacturing systems. According to Côte and Hall (1995), an industrial ecopark is an industrial system that conserves natural and economic resources; reduces the costs associated with production, materials and energy used, insurance and waste treatment; improves operating efficiency, quality, employee health and the public image; and provides opportunities for generating income through the use and sale of waste materials.

Industrial ecology and industrial ecoparks are linked to the concept of the cluster, i.e., the concentration of industries, services, activities and other agents that are connected to one another and able to create synergies. The proximity or joint location of the different agents that make up a cluster of these characteristics facilitates the use of their waste, by-products and energy surpluses and reduces transport and storage costs through the use of joint services. It also encourages innovation in cleaner production and waste-management technology and the creation of new industries, particularly ones that can use waste and by-products. Finally, it promotes the development of sustainable industrial production by adding value to the products and services. The greater the concentration of industries, the greater the opportunities for innovation and the creation of synergies [Roberts, 2004].

There are many examples of industrial ecoparks in the United States, Canada, Europe, Asia and Australia, although, to date, there are few documented cases in Spain. The island of Gran Canaria may be a good study setting for establishing an industrial ecopark, as its size (1560 km^2) means that the different industries that make up the ecopark are relatively close to each other without having to be located in the same industrial zone. Furthermore, the waste-treatment facilities on Gran Canaria are currently undergoing expansion and development [PIRCAN, 1999] and the ecopark could provide an alternative to the final disposal of waste in landfill sites and foster the creation of new waste-management plants.

2. Objectives

1. To consider and evaluate the feasibility, from an environmental perspective, of establishing an industrial ecopark.
2. To study the main flows of materials, energy and waste of the industries in the ecopark and establish a balance sheet of greenhouse-gas emissions and energy and water consumption for the industries and services that make up the industrial ecopark.
3. To determine which industries and process in the ecopark have the greatest environmental impact.
4. To propose synergies between the industries and services that make up the ecopark project: exchange of waste and by-products and use of shared facilities.
5. To quantify and evaluate the environmental improvements resulting from the creation of synergies between the industries.

3. Methods

To carry out this project, we used the materials and energy flow analysis (MEFA) method. MEFA is a method for the systematic evaluation of flows and stocks within a defined system in space and time [Brunner and Rechberger, 2004]. It involves analysing the performance of process chains, including the extraction or collection of raw materials, chemical transformation, manufacturing, consumption, recycling and final disposal of materials [Bringezu and Moriguchi, 2002]. The MEFA method uses the mass balance principle and is based on tallying the input and output of materials and energy (in units of mass and energy) of the system.

MEFA can be applied to industrial ecology studies and can examine the flows of materials and energy between an industrial system and the natural ecosystems with which it establishes connections. The method is used as an instrument to support decision making regarding the management of resources, waste and the environment [Brunner and Rechberger, 2004; Torres et al., 2008].

Although there is no general consensus regarding the MEFA methodological framework, the procedure followed tends to be similar and consists of the stages described below [Bringezu & Moriguchi, 2002; Brunner and Rechberger, 2004; Torres et al., 2008].

3.1. Study Objectives

To determine whether the creation of synergies and the exchange of by-products and waste between different industrial and economic activities, clustered in the setting of an industrial ecopark, reduces the environmental impact of these activities. Point 2 of this article lists the specific objectives.

3.2. Definition and limits of the systems

To carry out this study and meet its objectives, we decided to use a hypothetical case study on the island of Gran Canaria (Canary Islands), in which two study systems are compared. System S1 is a conventional industrial estate consisting of seven industries and nine different production processes (Point 3.3 and Table 1), which do not establish synergies between them. System S2 is an industrial ecopark, i.e., a cluster of industries and facilities that establish synergies between themselves. System S2 consists of the seven industries found in S1 but with 10 different production processes (Point 3.3 and Table 1). It also includes an energy-supply facility and a sports facility (Point 3.3 and Table 1).

3.3. Analysis of the Process Chain

Selection of Industries and Facilities

The selection of industries was made based on the most important industrial activities in Gran Canaria in production and economic terms. We also consulted the State Register of Emissions and Sources of Pollution [PTRT, 2007] to determine which Canary Island industries exceeded the threshold established by law (Royal Decree 508/2007, Ministry of the Environment, Spanish Government, 2007). Most of the proposed industries were already established and operating in the Canary Islands. We also proposed the creation of new industries and services with the aim of expanding synergies, thereby completing the cycle of waste, by-product and energy use. The main characteristics of the industries, facilities and processes considered are explained below.

1) <u>Polyethylene (PE) factory</u>: the plastic manufacturing and recycling industry is currently in operation on the island of Gran Canaria. This industry consists of

three different production processes, depending on whether System S1 or S2 is analysed.

- **System S1**: this consists of the manufacturing of virgin PE, i.e., by polymerization of ethylene.
- **System S2**: this consists of the process of recycling PE and manufacturing recycled PE chips. The recycled plastic material comes from separated packaging and containers in Gran Canaria and from the recovery of agricultural waste plastic (greenhouse covers, plastic mesh and bags from the banana bunches).

2) Injection-moulded plastics factory: this factory makes plant pots and multiple-pot trays for agricultural use. Gran Canaria already has several industries that transform and produce plastic products. The difference between the two study systems lies in the raw material used: system S1 will use virgin PE chips and S2 will use recycled PE chips.

3) Paper industry: this industry does not yet exist in the Canary Islands. This industry consists of four different production processes (Table 1), depending on whether system S1 or S2 is analysed.

- **System S1**: this consists of the manufacture of paper for packaging, such as kraftliner (linerboard) and semi-chemical fluting (paper for corrugating). Both types of paper are made from virgin cellulose fibres, i.e., fibres extracted from wood resources, which are mostly imported from the continent.
- **System S2**: this consists of the manufacture of paper for packaging, such as testliner (linerboard) and wellenstoff (paper for corrugating). In this case, both types of paper are made from recovered cellulose fibres, which are obtained from recycling paper and cardboard recovered in Gran Canaria. System S2 also involves using plant fibres from agricultural waste to obtain cellulose fibres and manufacture paper.

4) Corrugated cardboard box factory: there are several industries in Gran Canaria that manufacture corrugated cardboard boxes. The plant taken as an example specializes in the manufacture of corrugated cardboard and model P-84 corrugated-cardboard boxes, which are used to transport and export Canary Island tomatoes and other horticultural products. This industry includes two different industrial phases (Table 1): manufacture of corrugated cardboard using paper for packaging and manufacture of cardboard boxes (converting), which consists of printing, die-cutting, folding and gluing the boxes. The paper used as the raw material for the corrugated cardboard varies, depending on the system studied: paper from virgin fibre for System S1 and paper made from recycled fibre for System S2.

5) Canary Island tomato growing: agricultural activity in the Canary Islands focuses on exports of tomato and Canary Island bananas. Production of Canary Island tomatoes is mainly located on the island of Gran Canaria (59.42% of total production of Canary Island tomatoes) [Government of the Canary Islands, 2009]. The island dedicates 1027 ha to tomato growing, 920 ha of which are destined for export [Government of the Canary Islands, 2009]. These large production centres produce a large amount of biomass waste. The S1 and S2 study systems include the entire area of the island dedicated to protected tomato growing (1011 ha) [Government of the Canary Islands, 2009] in order to evaluate its environmental impact and look for synergies between agricultural activity and industrial activity.

6) Canary Island banana growing: banana growing in Gran Canaria is less widespread (19.31% of total production of Canary Island bananas) [Government of the Canary Islands, 2009]. A total of 1812 ha is dedicated to the crop on the island, of which 941 ha is protected growing [Government of the Canary Islands, 2009]. Due to the characteristics of the banana plant, this crop also generates a large amount of biomass waste. The S1 and S2 study systems include the entire area of the island dedicated to protected and open-air banana growing.

7) Biomass cogeneration plant: only 0.11% of the electricity used in Gran Canaria comes from cogeneration plants. The percentage for all the islands as a group is higher, at 2.54% [Government of the Canary Islands, 2006]. Cogeneration plants produce electricity and useful heat (steam, hot water and hot air) from the same primary source, which makes them more efficient than conventional thermal power stations. The cogeneration plant, which is included in System S2, will use the waste from tomato and banana crops and other fruit trees (Table 5) as fuel.

8) Sports facility: this is a 4500 m^2 sports centre with a swimming pools and a spa. There are several different facilities of these characteristics in Gran Canaria, such as the Las Rehoyas sports complex (Las Palmas, Gran Canaria). A facility of this type is included in the S2 study system, with the aim of using the waste heat of different industries in the ecopark to supply heat to the facility.

Table 1. list of industries, industrial processes and services that make up the industrial ecopark, with annual production figures.

INDUSTRIES	INDUSTRIAL PROCESSES	PRODUCTION	SYSTEM S1	SYSTEM S2
PAPER INDUSTRY	Manufacture of semi-chemical fluting	50,000 t/year	X	
	Manufacture of kraftliner	50,000 t/year	X	
	Manufacture of wellenstoff	50,000 t/year		X
	Manufacture of testliner	50,000 t/year		X
MANUFACTURE OF CORRUGATED CARDBOARD BOXES	Manufacture of double-layer corrugated cardboard	11,035 t/year	X	X
	Production of corrugated cardboard boxes (printing, die-cutting, folding and gluing)	11,035 t/year = 28,225,506.4 boxes/year	X	X
POLYETHYLENE (PE) FACTORY	Manufacture of virgin PE	15,000 t/year	X	
	PE recycling	15,000 t/year		X
	Manufacture of recycled PE	15,000 t/year		X
INJECTION-MOULDED PLASTICS FACTORY	Manufacture of plastic plant pots and multiple-pot trays	4000 t/year	X	X
TOMATO GROWING	Production of greenhouse Canary Island vine tomato	93,307 t/year	X	X
BANANA GROWING	Production of open-field Canary Island banana	32,718.26 t/year	X	X
	Production of greenhouse Canary Island banana	35,347.74 t/year	X	X
COGENERATION PLANT	Production of electricity generated from biomass waste	21,000 MWh/year = 75,600,000 MJ/year		X
	Production of heat generated from biomass waste	25,100 MWh/year = 90,500,000 MJ/year		X
SPORTS FACILITY	Sports facility with swimming pools and spa	Area of 4500 m^2		X

3.4. Data Acquisition

Obtaining data on the input and output flows relating to the processes being studied was performed by consulting different sources of information (Table 2). For industrial production (Table 1), we consulted industries in the sector established in the Canary Islands.

Table 2. Source of data relating to each of the industrial processes and facilities studied.

INDUSTRIAL PROCESSES	PHASES TAKEN INTO ACCOUNT	SOURCE OF DATA
Paper industry and manufacture of corrugated cardboard boxes	Paper mill and industrial facilities, machinery, raw materials used and auxiliary materials, facilities for selecting recovered raw materials, transport, energy and water consumption	- *European Database for Corrugated Board Life Cycle Studies* (FEFCO and CEPI, 2009) - Industries in the sector - *Ecoinvent database* v.2.2
PE-manufacturing and plastic injection moulding processes	Raw materials used, auxiliary materials, transport, energy and water. Only the machinery used to manufacture injection-moulded plastics is included	- *Ecoinvent database* v.2.2
PE recycling process	Raw materials used, auxiliary materials, transport, energy and water use	- Perugini et. al 2005 - Industries in the sector
Protected Canary Island tomato growing	Infrastructure, auxiliary equipment, fertilizers, waste management, seedbeds, cultural operations, air conditioning and pesticides	- Canary Island Agricultural Research Institute (ICIA, 2011)
Protected and open-air Canary Island banana growing	Infrastructure, auxiliary equipment, fertilizers and waste management	- Canary Island Agricultural Research Institute (ICIA, 2011) - Ritter et al., 2009
Cogeneration plant	Cogeneration facility and machinery, auxiliary materials, transport, energy and water	- *Ecoinvent database* v.2.2 - Puy, N., 2006
Sports facility	Energy used by the facility	- Industries in the sector
Energy production in the Canary Islands	Electricity production using different sources of energy	- Canary Islands Energy Plan (PECAN, 2006)
Water desalination for industrial use		- Antón et al., 2009

The data referring to collection of urban waste and generation of agricultural waste in Gran Canaria are estimated. Tables 3, 4 and 5 show the different sources consulted in order to calculate these estimates, together with the final estimated values.

3.4.1. Quantification of urban waste generated in Gran Canaria that can be used by the Industries in the Industrial Ecopark

We calculated the estimated value of paper, cardboard and plastics from waste separation in Gran Canaria with the aim of considering the use of this waste as a raw material in the different processes of the industrial ecopark (S2).

Some 29,616.6 t of paper and cardboard waste is collected in Gran Canaria each year (Table 3) and this is sent to be recycled outside the Canary Islands. It is also estimated that non-separated domestic waste collected in Gran Canaria contains

80,026.8 t/year of paper and cardboard waste (Table 3), which could be recovered for subsequent recycling. These figures mean that it would be possible to recover 109,643.4 t/year of paper and cardboard, which represents 98.4% of the consumption of paper and cardboard in Gran Canaria (Table 3).

In terms of plastic, 23,726.5 t/year of plastics is collected via waste separation of containers and packaging in Gran Canaria (Table 3). This waste, which is largely recycled on the island, could provide the raw material needed to manufacture plant pots, multiple-pot trays, boxes, mesh and other plastic products used in agriculture in the Canary Islands.

Table 3. Estimated Values of Urban-Waste Generation and Use of Paper and Cellulose in Gran Canaria.

DATA TYPE	INFORMATION SOURCES	ESTIMATED VALUE
Use of paper and cardboard in Gran Canaria (2009)	- Use of paper and cardboard in Spain (2009): 6,213,300 t/year (Industrial Observatory of the Paper Industry, 2011). - Spanish population (2009): 46,745,807 (INE, 2011). - Population of Gran Canaria (2009): 838,397 (ISTAC, 2011).	111,437 t/year
Use of cellulose in Gran Canaria (2009)	- Use of cellulose in Spain (2009): 1,743,400 t/year (Industrial Observatory of the Paper Industry, 2011). - Spanish population (2009): 46,745,807 (INE, 2011). - Population of Gran Canaria (2009): 838,397 (ISTAC, 2011).	30,940.1 t/year
Use of cellulose in Gran Canaria (2009)	- Use of cellulose in Spain (2009): 1,743,400 t/year (Industrial Observatory of the Paper Industry, 2011). - Spanish population (2009): 46,745,807 (INE, 2011). - Population of Gran Canaria (2009): 838,397 (ISTAC, 2011).	30,940.1 t/year
Paper and cardboard collected from waste separation in the Canary Islands (2008)	- Canary Islands Institute of Statistics (ISTAC, 2011)	72,907 t/year
Paper and cardboard collected in Gran Canaria (2008)	- Rate of paper and cardboard collection in the Canary Islands (2008): 35.7kg/inhabitant/year (ISTAC, 2011). - Population of Gran Canaria (2008): 829,597 inhabitants/year (ISTAC, 2011).	29,616.6 t/year
Non-separated paper and cardboard waste contained in urban solid waste (USW) in Gran Canaria (2008)	- Rate of non-separated USW collection in the Canary Islands (2008): 511.9 kg/inhabitant/year (ISTAC, 2011). - Population of Gran Canaria (2008): ISTAC, 2011. - % of paper and cardboard waste in USW: 19.4% (Government of the Canary Islands, 2001).	80,026.8 t/year
Mixed containers and packaging collected in Gran Canaria (2008)	- Rate collection of mixed containers and packaging in the Canary Islands (2008): 28.6 kg/inhabitant/year (ISTAC, 2011). - Population of Gran Canaria (2008): ISTAC, 2011.	23,726.5 t/year

3.4.2. Quantification of agricultural waste generated in Gran Canaria that can be used by the Industries in the Industrial Ecopark

Here, we have estimated the annual generation of biomass waste produced by the annual harvesting and pruning operations on the most widespread crops in Gran Canaria: tomato, banana and fruit trees. In the case of banana and tomato, reject fruit was also taken into account.

We also calculated the generation of plastic waste associated with replacing the greenhouse covers of the protected crops: tomato and other vegetable crops, banana and other fruit trees, and flowers and ornamental plants. Here, too, we have included the plastic waste from the plastic bags used to wrap the banana bunches on the banana plants, which is an increasingly widespread technique in the Canary Islands [PIRCAN, 1999].

Table 4. Crop Areas and Production of Some Crops in Gran Canaria.

DATA TYPE	INFORMATION SOURCES	ESTIMATED VALUE
Tomato-growing area in Gran Canaria (2009)	- Protected growing area (PGA) and open-air growing area (OAGA): Government of the Canary Islands, 2009.	PGA: 1011 ha OAGA: 16 ha
Banana-growing area in Gran Canaria (2009)	- Protected growing area (PGA) and open-air growing area (OAGA): Government of the Canary Islands, 2009.	PGA: 941 ha OAGA: 871 ha
Protected growing area for other vegetable crops in Gran Canaria (2009)	- Government of the Canary Islands, 2009.	499 ha
Protected growing area for flowers in Gran Canaria (2009)	- Government of the Canary Islands, 2009.	77 ha
Fruit-tree growing area in Gran Canaria, except bananas (2009)	- Protected growing area (PGA) and open-air growing area (OAGA): Government of the Canary Islands, 2009.	PGA: 120 ha OAGA: 2019 ha
Tomato growing in Gran Canaria (2009)	- Government of the Canary Islands, 2009.	93,307 t/year
Banana growing in Gran Canaria (2009)	- Government of the Canary Islands, 2009.	68,066 t/year

Biomass Waste

Because tomato growing takes up the greatest area on the island (1027 ha) [Government of the Canary Islands, 2009], it also generates the largest amount of biomass: 40,440 t/year (Table 5). It should be taken into account that the biomass waste from tomato growing is very wet (85% humidity) and, therefore, the useful dry residue is reduced to 6066 t/year (Table 5). Furthermore, tomato growing also generates 1116 t/year dry weight of rejected fruit (Table 5).

This is followed by banana growing, with 1812 ha [Government of the Canary Islands, 2009]. Banana growing is estimated to produce 9295.6 t/year of biomass waste (leaves, pseudostem and rachis) and 6806.6 t/year of rejected fruit (Table 5).

Finally, pruning waste from other fruit-tree crops in Gran Canaria (orange and other citrus fruits, avocado, papaya, mango, pineapple, grape and others) [Government of the Canary Islands, 2009] generates 3308.4 t/year in dry weight (40% humidity) [Puy, N] of biomass waste (Table 5).

Table 5. Estimated Values of Agricultural Waste Generation (Biomass and Plastics for Protected Crops) in Gran Canaria.

DATA TYPE	INFORMATION SOURCES	ESTIMATED VALUE
Agricultural waste from banana growing (2009)	- Banana-growing area in Gran Canaria (2009) Government of the Canary Islands, 2009. - Waste-generation coefficient for banana growing: 6.84 t/ha with 75% availability (PIRCAN, 1999).	Fresh weight: 9295.6 t/year
Waste from banana selection (2009)	- Banana growing in Gran Canaria (Government of the Canary Islands, 2009). - Mean % of bananas rejected: 10% (ICIA-Biomusa Project).	Fresh weight: 6806.6 t/year
Agricultural waste from protected tomato growing (2009)	- Protected tomato-growing area in Gran Canaria (2009) Government of the Canary Islands, 2009. - Waste-generation coefficient for protected tomato growing: 40 t/ha (PIRCAN, 1999). - % humidity of tomato biomass waste: 85%	Fresh weight: 40,440 t/year Dry weight: 6066 t/year
Waste from tomato selection (2009)	- Tomato growing in Gran Canaria (Government of the Canary Islands, 2009). - Mean % of tomatoes rejected: 9.62% at production site and 2.53% in packing plant (Government of the Canary Islands, 2009). - % humidity in rejected tomatoes: 90%	Fresh weight: 11,160.2 t/year Dry weight: 1116 t/year
Agricultural waste from pruning of fruit trees (2009)	- Fruit-tree-growing area (except bananas): Government of the Canary Islands, 2009. - Waste-generation coefficient for fruit-tree pruning: between 1.5 t/ha and 3.5 t/ha (depending on type of tree studied), with 90% availability (PIRCAN, 1999). - Mean % humidity of fruit-tree wood: 40% (Puy, N., 2006).	Fresh weight: 5514 t/year Dry weight: 3308.4 t/year
Plastic waste from replacement of greenhouse covers (2009)	- Protected growing area in Gran Canaria (2009): Government of the Canary Islands, 2009. - m^2 plastic/m^2 of greenhouse (depending on crop): PIRCAN, 1999. - g plastic/m^2 of plastic (depending on cover: mesh or film): PIRCAN, 1999. - Number of banana plants/ha: 1800 (PIRCAN, 1999). -g plastic/banana-bunch bag: 62.1 (PIRCAN, 1999).	Waste film: 1070.8 t/year Waste mesh: 372 t/year Banana-bunch bag waste*: 202.5 t/year.

*Considering that all banana plants use this technique.

Waste Plastic

Protected growing of tomatoes, which represents 98.4% (Table 4) of the area dedicated to tomato growing in Gran Canaria, generates an annual average of 254.8 t/year of polyethylene mesh (Table 5). Other protected vegetable crops (499 ha) [Government of the Canary Islands, 2009] produce an annual average of 275.4 t/year of polyethylene film and 26.2 t/year of mesh (Table 5).

Protected banana growing (941 ha) [Government of the Canary Islands, 2009] produces an annual average of 678.7 t/year of film, 83 t/year of mesh and 202.5 t/year of plastic bags for banana bunches (Table 5). Other protected fruit-tree crops (120 ha) [Government of the Canary Islands, 2009] produce an annual average of 88.3 t/year of film (Table 5).

Finally, protected growing of flowers and ornamental plants (77 ha) [Government of the Canary Islands, 2009] produces annual average waste of 28.3 t/year of film and 8.1 t/year of mesh (Table 5).

All these crops produce 1645 tonnes of plastic annually, which could be recovered, recycled and used to manufacture plastic products.

3.5. Modelling: Environmental Evaluation Method

In order to evaluate the environmental impacts associated with the processes, industries and facilities of study systems S1 and S2, we used the life-cycle analysis (LCA) program, SimaPro v.7.3 to analyze the classification and characterization stages (defined as compulsory by ISO 14040). The environmental-evaluation methods used were those of the IPCC (Intergovernmental Panel on Climate Change) in the contribution of the impact on global warming (GW) and the Cumulative Energy Demand (CED).

3.5.1. Global Warming: Calculation of Greenhouse Gas Emissions

Emissions of greenhouse gases (CO_2, N_2O, CH_4, SF_6, HFCs, HCFCs and CFCs, as set out by the Kyoto protocol) in the processes, industries and facilities of study systems S1 and S2 are given in equivalent kg of CO_2, in accordance with the conversion factors established by the IPCC. Biogenic CO_2 emissions have been excluded from the calculation.

3.5.2. CED Impact Category: Calculation of Energy Use

To calculate the total amount of energy resources used by each industry and facility in Systems S1 and S2, we used the Cumulative Energy Demand (CED) indicator. The aim of cumulative energy requirement analysis (CERA) is to investigate the use of energy throughout the life cycle of a good or service. This includes the energy used directly by the use of the product or service, but it also includes the energy used indirectly, such as that used in extracting the raw materials or in manufacturing materials [Frischknecht et al., 2007]. We counted all inputs of fossil-fuel use (coal, peat, petroleum, natural gas, uranium) and energy from renewable sources (biomass, wind, solar and hydroelectric). The data obtained from calculating the CED can be used to detect priorities in energy saving for a product or service in the design, production, use and disposal phases. The CED is also used as an indicator of detection of environmental impacts [Frischknecht et al., 2007].

3.5.3. Calculation of Water Use

To carry out this calculation, we considered all water inputs to each of the industrial processes analysed. The volume of waste water generated by the main industries in Systems S1 and S2 will also be taken into account in order to evaluate its re-use.

4. Results

4.1. Comparative Environmental Analysis of Systems S1 and S2

The results in Table 6 show that System S2 has lower associated atmospheric CO_2 emissions and energy and water consumption than S1. The percentages of reduction between S2 and S1 range between 7% and 41%. This reduction in environmental impacts in System S2 is related to the use of recycled raw materials, by-products and waste generated in the context of the industries that make up the industrial ecopark in Gran Canaria (Table 1).

Table 6. Environmental Impacts of System S1 and System S2. S1 = industrial estate with no synergies between the industries and facilities; S2 = industrial ecopark, where the industries and facilities establish synergies between each other.

ENVIRONMENTAL INDICATORS	SYSTEM S1	SYSTEM S2	REDUCTION OF S2 COMPARED TO S1 (%)
Equivalent CO_2 emissions (Gg CO_2)	434.9	389.1	**10.5**
Energy consumption (TJ)	9110.6	5374.1	**41**
Water use (hm^3)	342.8	294.7	**14**
Heat loss (TJ) (waste heat)	4905.9	4542.4	**7.4**
Heat loss (TJ) to water	312.8	249.9	**20.1**

Tables 7 and 8 show the annual CO_2 emissions and energy and water use for Systems S1 and S2 by processes analysed and based on production. In both systems, the processes with the greatest environmental impact are PE manufacturing, banana growing and paper manufacturing. These three processes are those with the greatest impact on the system, whether the parameters studied are calculated based on annual production or per kilogramme of product.

4.2. Use of Recycled Raw Materials

One of the synergies included in S2 is the use of recycled raw materials from the collection of separated urban waste in Gran Canaria. Hence, the paper industry, manufacturing of corrugated cardboard boxes and the plastics industry (PE manufacturing and injection-moulded plastics) have used recycled materials in their industrial processes.

The use of **recycled paper and cardboard** reduces the CO_2 emissions associated with the manufacture of paper required to produce a box by 22.9% and the CO_2 emissions associated with the manufacture of a box by 14.1%. The energy demand for the manufacture of the recycled paper contained in the box is 68.6% lower than for the manufacture of virgin paper. This means that manufacturing a box with recycled paper leads to a reduction in energy use of 51.5%. Recycled paper also reduces water use in the manufacturing process (31.5%), in comparison with virgin paper and, as a result, a box made from recycled paper uses 59.5% less water than a box made from virgin paper.

Another proposal is the use of **recycled plastic** in the manufacture of PE chips, which are then used to manufacture plant pots and multiple-pot trays for agricultural use. In this case, the PE recycling process emits 19.4% less CO_2 than the process for manufacturing virgin PE. The energy demand of recycling PE is also lower (37.6% lower than that of manufacturing virgin PE). The PE recycling process uses 2.5% more water than the manufacture of virgin PE. These values mean that, overall, the manufacture of plastic products using recycled PE has 16.5% lower associated emissions of CO_2 than the manufacture of plant pots using virgin PE, and uses 32.9% less energy.

4.3. Use of Biomass Waste From Agricultural Activity

The waste and by-products from agricultural activity, estimated in Point 3.4.2., can be used in different ways in System S2.

4.3.1. Agricultural Waste From Bananas as a Source of Cellulose

A total of 9295.6 t/year of agricultural waste from banana production (leaves, pseudostem and rachis) is generated in Gran Canaria (Table 5). In most plantations, this vegetable waste is added to the soil. In S2, this waste would be used to manufacture paper and cardboard, as some authors [Reddy et al., 2005] state that the fibres may contain as much as 65% cellulose. Different authors [Cordeiro et al., 2004; Canché et al., 2005; Reddy et al., 2005; Turrado et al., 2009] have carried out studies on obtaining cellulose from banana-plant waste and have confirmed that it can be used in paper manufacturing. According to these studies, in the best-case scenario, the fibres from banana-plant waste could provide 6000 t/year of cellulose (19.5% of the estimated consumption of cellulose in Gran Canaria) (Table 3). With this amount of waste, it would be possible to manufacture 70 tonnes of paper per year [Jing Yang Tock], i.e., 0.06% of the paper and cardboard used in Gran Canaria.

4.3.2. Waste From Rejected Bananas and Banana Skins as a Source of Energy

Research also exists that has calculated the energy potential of banana waste [Clarke W.P. et al., 2008; Tock J.Y. et al., 2010]. Clarke studied the production of methane from rejected bananas (those that do not meet the quality requirements for subsequent sale) using an anaerobic-digestion system. Tock compared the energy potential of different types of banana waste (pseudostem, leaf and rachis, banana skins and rejected bananas) and compared direct-combustion and anaerobic-digestion systems. Both studies corroborate the fact that bananas have considerable energy potential and that better results are obtained with anaerobic-digestion than with combustion.

Thus, based on the data published by Tock J.Y. (2010), the energy potential of both types of waste has been estimated for Gran Canaria. The results show that **direct combustion** of the 9295.6 t/year of banana agricultural waste (Table 5) has an energy potential of 121.8 TJ (2.3% of the energy demand of the whole of System S2) (Table 6). Direct combustion of the bananas rejected annually in Gran Canaria (6806.6 t/year) (Table 5) would provide 514.3 TJ (9.6% of the energy demand of the whole of System S2) (Table 6). **Anaerobic digestion** takes into account the waste from the bananas rejected annually in Gran Canaria (Table 5) and the skins produced (40% of the weight of the banana) [Monsalve, 2006] annually through the consumption of bananas in Gran Canaria (12,773.9 t/year) [Government of the Canary Islands, 2009]. Digestion of the rejected bananas would produce a potential 1609.9 TJ of energy (30% of the energy demand of S2) and digestion of the skins would produce 654.3 TJ (12.2% of the energy demand of S2).

In conclusion, the energy from this agricultural waste could supply up to 2386 TJ, i.e., 44.4% of the energy demand of S2 (Table 6).

4.3.3. Using Energy From Agricultural Waste From Tomatoes

System S2 includes a cogeneration plant with the aim of using the agricultural waste produced in Gran Canaria as a raw material. In this study, we have calculated only the energy potential of the agricultural waste and reject waste from tomato growing and the agricultural waste produced by pruning fruit trees (Table 5). This biomass, estimated in Point 3.4.2., is considered to be in the form of chips, which have a lower heating value (LHV) of 18 MJ [Puy, 2006].

The dry waste from tomato growing could provide 137.1 TJ and the dry waste from fruit-tree pruning could provide 59.5 TJ. Together, they could generate 3.7% of the energy used in S2 in the form of electricity and heat.

4.4. Use of Excess Waste Heat In Municipal Facilities and Services

Together, the industrial processes that make up the industrial ecopark generate a loss of 4542.4 TJ of heat (Table 6), which dissipates into the air, water and soil. The heat that dissipates into the water (approximately 5%) (Table 6) could be used to provide hot water and heating for some municipal facilities and services in S2. The industrial ecopark project includes a sports complex with an area of swimming pools and spa, measuring 4500 m^2, which could be heated entirely using waste heat. Through consultations with companies in the sector, we have established that an annual use of 6 TJ/year would be required for facilities of this type, which is only 2.4% of the heat that dissipates into the water in S2. This would lead to savings of 160 m^3 of fuel oil and prevent the emission into the atmosphere of 0.6 Gg of equivalent CO_2.

As the amount of waste heat is very large, it could also be used to supply energy in the form of steam to the industries in the industrial ecopark. For example, according to data from industries in the sector, the manufacture of corrugated cardboard boxes uses an average of 11 TJ/year of steam (4.4% of the heat that dissipates into the water in S2) (Table 6) and this steam could therefore be provided by the waste heat produced in S2.

5. Discussion

This study has put forward an initial prospection of the environmental advantages provided by establishing an examplerized case study: an industrial ecopark in Gran Canaria.

As stated in the introduction section of this study, different factors make Gran Canaria an ideal island for establishing an industrial ecopark.

- First, the small size of the island (1560 km^2) in comparison with the continent means that the exchange of waste, by-products, energy and water between the different parties involved in the industrial ecopark is feasible, even though they are not in the same industrial area.
- Second, the lack of waste-recovery facilities and the fact that it is an island mean that it is even more important for the industries of Gran Canaria to re-use and recover the maximum amount of by-products, waste, waste energy and waste water possible.
- Finally, establishing an industrial-agricultural ecopark in Gran Canaria may encourage new business and market opportunities. This is an important point, as the economy of Gran Canaria is largely based on tourism and agricultural exports, and the latter have fallen in recent years due to increased competition.

It has been found that the activities with the highest use of natural resources and the highest emissions of CO_2 are greenhouse production of Canary Island bananas (mainly due to the use of fertilizers and to the water requirements of the crop), the production of paper for manufacturing corrugated cardboard boxes, and the manufacture of PE. These are the main processes in which we have attempted to reduce the associated environmental impacts.

The use of recycled raw materials (paper and plastic) from the collection of separated waste creates synergies between the urban system, the paper industry and the plastics industry. It reduces CO_2 emissions by 10.5%, energy use by 41% and water use by 14% (Tables 6, 7 and 8). Furthermore, with the annual production of paper and cardboard boxes established in the industrial ecopark, the consumption of wood would be reduced by 440,200 m^3 [Ecoinvent database v.2.2]. Moreover, while not evaluated in this study, it is believed that establishing these synergies may lead to economic savings, as, in the specific case of paper, the Canary Islands import most of their timber resources and export the waste from paper production to the mainland for subsequent recycling. With regard to the raw material used to manufacture recycled PE, in S2, we propose using waste containers and packaging from collected separated waste, and agricultural plastic waste. Large amounts of agricultural plastic waste are produced each year, which does not degrade and which ends up accumulating in the fields. This leads to degradation of the landscape, land occupation and, when burnt, air pollution [PIRCAN, 1999]. For these reasons, it is important that this waste be managed properly and re-using it in the plastic-recycling industry is a good option that means that this waste can be used as a raw material.

In System S1, agricultural plant waste (vegetable biomass waste and rejected fruit) produced by crop growing is sent to the landfill site. In System S2, this waste is given a new use in order to reduce environmental impacts. In general, the contribution of not sending waste to the landfill site is practically negligible (approximately 0.01%) (Tables 7 and 8) in relation to the final values of the environmental indicators studied (Table 6) and in comparison with the use of recycled paper and plastic. However, re-using this agricultural waste reduces the use of raw materials and fossil fuels. The waste produced in agricultural operations is currently not used or required by any sector. In most cases, it remains in the field until it has fully decomposed, is burned in the field, or is used as food for livestock [PIRCAN, 1999]. In protected crops, the plastic string may pose a risk to livestock if eaten. In some cases, large quantities of rejected fruit may also lead to outbreaks of pests and unpleasant odours. For these reasons, the waste should be removed from all sufficiently large plots of land. PIRCAN (1999) proposed removing, chipping and using agricultural waste for energy production, particularly fibrous and woody waste.

This study has put forward a use for agricultural waste other than energy production, in compliance with the waste hierarchy established by Directive 2008/98/CE of the European Parliament and of the Council of 19 November 2008 on waste. We therefore considered using the fibres of banana waste (pseudostem, leaves and rachis) as a source of cellulose for manufacturing paper, instead of using it to produce energy through direct combustion. In this way, the boxes used to export horticultural products could be made using horticultural waste. According to TNF Ecopapers – The banana paper company (2011), environmentally friendly banana paper is made with 10% cellulose from banana fibres and 90% cellulose from recycled paper. Hence, the 6000 t/year of cellulose (19.5% of estimated cellulose use on the island) (Table 3) from waste from the banana plant could supply 6% of annual paper production (Table 1). Because the manufacture of paper using waste from the banana plant is very similar to the manufacture of recycled paper, the environmental impacts avoided are considered to be the same, except for the avoided impact of sending more than 9000 t/year to the landfill site, which, as mentioned above, is practically negligible.

Apart from paper manufacturing, the fibrous and non-fibrous banana waste can be used to make flour for baking, bread, powdered milk, starch, crisps and preserves, alcoholic drinks and dyes [Mazzeo et al., 2010; Cantó et al., 2011]. This study does not analyse the use of by-products of banana growing in the preparation of these products. However, it is worth mentioning in regard to future studies, as this might help diversify the economy of Gran Canaria and open new markets.

In terms of energy production from agricultural banana waste, anaerobic digestion of rejected bananas would provide the equivalent of 30% of the energy use of S2. This waste would thus indirectly prevent the emission of 152.4 Gg of CO_2 associated with the use of electricity from the Canary Islands mix. Furthermore, if the skins of bananas eaten in Gran Canaria could be recovered by means of a waste-separation system, they could supply 42.1% of the energy use of S2 and prevent a further 61.9 Gg of CO_2 emissions associated with the use of electricity from the Canary Islands mix.

Finally, the waste from tomato growing and from pruning fruit trees could supply enough raw material for the annual production of the S2 cogeneration plant. It would provide 196.6 TJ (3.7% of the energy demand of S2) and would, indirectly, prevent the emission of 36.8 Gg of CO_2 associated with the use of electricity from the Canary Islands mix. In summary, using the plant waste from tomatoes and fruit trees and rejected tomatoes and bananas could provide almost 50% of the energy use of S2 and reduce CO_2 emissions in S2 by 64.5% more than the values shown in Table 6.

It should be noted that 4.6% of the energy used in the ecopark is dissipated in the form of waste heat and that this can be used to provide hot water, steam and heating for the industries and services in the ecopark, as the output temperature is, in most cases, between 90ºC and 50ºC. The results show that this waste heat can fully meet the heat demand of the sports facility and the paper industry.

Finally, many industrial ecopark projects promote the use of shared facilities and services by the different members. However, as it was pointed by Ge et al. (2011 agroparks may fail to materialize due to the high institution cost of establishing and maintaining the collaboration among different stakeholders. The key to successful formation and operation of an agropark is therefore the choice of proper institutional arrangements which create high incentives to cooperate and incur low institution cost. In the particular case of this study, we consider convenient to propose creating shared warehouses, cold-storage facilities for agricultural products, shared packing equipment and transport, as well as the aforementioned energy facilities.

6. Conclusions

As a conclusions we can remark the potential to recover agricultural waste and by-products as raw materials between the industries and services that make up the agricultural-industrial ecopark; such practises reduce the environmental impact of these industrial activities (use of resources, waste production and emission of polluting gases). In turn, this establishes links between the industrial activities, the agricultural sector and the society. Regarding the case study developed we can conclude that the paper industry, the plastics industry and banana growing are the industrial processes with the greatest associated environmental impact per unit of product produced. The industrial-agricultural ecopark project would produce competitive products with added value, could provide an opportunity for new industries and help to drive the local economy, and would raise environmental awareness among producers and consumers.

We have presented here a preliminary prospective on the subject of greenhouse clustering; this has proven to be an interesting approach in terms of environmental, economic and social sustainability. This study can be considered as a starting point from which further research studies can be developed in the future.

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Table 7. **Environmental impacts of industries and activities in the system S1 (S1 = industrial area without establishing synergies between industries and facilities)**

INDUSTRIES /ACTIVITIES S1	INDUSTRIAL PROCESSES S1	CO_2 emissions (Gg CO_2/year)	Energy consumption (TJ/year)	Water consumption (hm^3/año)	Residual Heat (TJ)	Water residual heat (TJ)
PAPER INDUSTRY	Manufacture kraf*tliner*	45.7	2,272.9	50.2	761	72.1
	Manufacture *semichemical fluting*	59	1,917.5	36.8	816.6	50.4
	Total	104.7	4,190.4	87	1,577.6	122.5
MANUFACTURE OF CORRUGATED CARDBOARD BOXES (CO)	Manufacture of double-layer corrugated cardboard CO	1.8	32.6	2.8	23.9	1
	Production of corrugated cardboard boxes (printing, die-cutting, folding and gluing)CO	5.6	118.4	5.4	93	12.1
	Total procesos CO	7.4	151	8.2	116.9	13.2
POLYETHYLENE (PE) FACTORY (PE)	Manufacture of virgin PE	127.1	2,853.5	119.7	1,806.9	27.8
INJECTION-MOULDED PLASTICS FACTORY	Manufacture of plastic plant pots and multiple-pot trays	6.12	109.8	3	95	11.4
TOMATO GROWING	Production greenhouse tomato	67	838.7	56.8	541.7	56.9
BANANA GROWING	Production of greenhouse banana	70	583.9	49.7	463.1	44.1
	Production open-field banana	52.7	383.2	18.5	304.8	37
	Total banana production	122.7	967.1	68.2	767.9	81.1
TOTAL	**Total of whole process**	**434.9**	**9,110.6**	**342.9**	**4,906**	**312.8**

Table 8. **Environmental impacts of industries and activities in the system S2, (S2 = industrial eco-cluster, industries and facilities where synergies established between them).**

INDUSTRIES /ACTIVITIES S1	INDUSTRIAL PROCESSES S2	CO_2 emissions (Gg CO_2/year)	Energy consumption (TJ/year)	Water consumption (hm^3/año)	Residual Heat (TJ)	Water residual heat (TJ)
PAPER INDUSTRY	Manufacture *testliner*	41.5	647.4	17.3	659.9	21.7
	Manufature *wellenstoff*	41.4	643.8	16.8	656.5	21.4
	Total	82.9	1,291.2	34.1	1,316.4	43.1
MANUFACTURE OF CORRUGATED CARDBOARD BOXES (CO)	Manufacture of double-layer corrugated cardboard CO	1.8	32.6	2.8	23.9	1.1
	Production of corrugated cardboard boxes (printing, die-cutting, folding and gluing)CO	5.6	118.4	5.4	93	12.1
	Total procesos CO	7.4	151	8.2	116.9	13.2
POLYETHYLENE (PE) FACTORY (PE)	PE recycling	102.3	1,780.3	122.7	1,479.4	43.9
INJECTION-MOULDED PLASTICS FACTORY	Manufacture of plastic plant pots and multiple-pot trays	6.12	109.8	3	95	11.4
TOMATO GROWING	Production greenhouse tomato	67*	838.4*	56.8*	541.5*	56.9*
BANANA GROWING	Production of greenhouse banana	70*	583.3*	49.6*	462.4*	44.1*
	Production open-field banana	52.7*	383.2*	18.5*	304.7*	37*
	Total banana production	122.7	966.5	68.1	767.1	81.1
Planta de cogeneración	Production of electricity generated from biomass waste	0.4	109.2	0.9	104.7	0.2
	Production of heat generated from biomass waste	0.3	127.7	0.8	121.4	0.1
	Total processes	0.7	236.9	1.7	226.1	0.3
Instalaciones deportivas	Sports facility with swimming pools and spa					
TOTAL	**Total todos los procesos analizados**	**389.1**	**5,374.1**	**294.6**	**4,542.4**	**249.9**

*Residus impacts to carry landfill S2 have been eliminated from S2, because of they are recycled in others processes

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