Fuel 371 (2024) 131848

Contents lists available at ScienceDirect

Fuel

journal homepage: www.elsevier.com/locate/fuel

Full Length Article

Bioethanol from canary banana waste as an energy source to reduce the carbon footprint of island electricity systems

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ARTICLE INFO

Keywords:
Canarian banana
Bioethanol
Energy policy
Renewable energy
Island electricity systems (IESs)

ABSTRACT

Energy sovereignty and carbon footprint mitigation are challenges faced by island electricity systems (IES), along with the promotion of renewable generation systems. One of the aspects that can improve this is the development of specific actions in the recovery of agricultural waste as biofuels. Among them, the banana residue stands out, as it is the majority in agricultural production in the Canary Islands. On the other hand, biofuels are alternatives to fossil fuels that contribute to reducing greenhouse gas emissions. This article studies the potential of waste, the transformation of the existing sugars in the fruit waste of the Canarian banana to transform it into a 100% renewable fuel, bioethanol and, therefore, the environmental impact that it has on banana production, its new carbon footprint.

1. Introduction

Island Electrical Systems (IES) [1–3] in particular, the Canary Islands electricity system suffers from a low penetration of renewable energies [4,5], which has led to a low mitigation of the carbon footprint in electricity generation compared to the national mainland and has led to studies [4] in which the possibility of diversification of the energy mix with a greater penetration of renewable energies with the introduction of variables such as hydroelectric energy storage systems is highlighted [5], or by the application of alternative fuels from other fossil sources but with a lower emission of greenhouse gases [4]. Currently the consumption of renewable energies in the Canary Islands is far from the European targets, the reality of the Canary Islands is that the percentage of consumption of renewable energies is currently set at 19.0 %, [6] he Canary Islands depend on the outside world since, of renewable energy sources, wind, solar, hydroelectric, oceanic, geothermal, biomass and biofuels, only wind and solar have a place [7,8]. And based on these two, wind and solar, the consumption of fossil fuels is gradually decreasing, but very slowly. Thus, fuel inputs to the Canary Islands for consumption have been decreasing since 2017 with 7.1 million tonnes, compared to 3.5 million tonnes in 2020. It is worth noting the weight of diesel in the Canary Islands, which accounted for 43.57 % of consumption, and fuel oil, which accounted for 31.27 % of consumption in 2020 [6] (Table 24). On the other hand, the evolution of greenhouse gas emissions in the Canary Islands, by category, indicates a decrease from 2005 with emissions of 17.6 million tCO_{2eq} to 2019 with emissions of 13.0 million tCO_{2eq}., which represents a decrease from 2005 to 2019 of 25.9 %. Specifically in agriculture, this value has been fluctuating, obtaining, according to date, its maximum in 2001 with 299,520.0 tCO_{2eq}, and its minimum in 1991 with 180,850.0 tCO_{2eq}. In 2019 its value was 187,400.0 tCO_{2eq}, which represents a decrease of 37.4 % from 2001 to 2019. (Appendix, Table 25) [6]. Ideas and initiatives to stop, even partially, this pollution problem require global solutions [9], or as the European Union points out [10,11] region-specific solutions. Among others, (a) elimination or partial substitution of fossil fuels with less polluting fuels, (b) partial substitution of fossil fuels with alternative fuels, such as biofuels or synthetic fuels, e-fuel, with zero net pollutant emissions, zero net tCO_{2eq}, (c) increasing the use of renewable energies, (d) use of 100 % biodegradable products, (e) recovery of waste, etc. Both in continental areas [9], as in island environments and specifically in the Canary Islands, there are specific actions that can help achieve the environmental objective, such as the recovery of agricultural waste and its contribution to the environment, and specifically the recovery of bananas. Globally, bananas represent the most important fruit crop in the world [9], Generating each ton of bananas produced, 2.13 tons of waste are generated [12,13]. It is the most exported fresh fruit in the

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https://doi.org/10.1016/j.fuel.2024.131848
Received 11 March 2024; Received in revised form 26 April 2024; Accepted 7 May 2024

world in terms of volume and value [9]. This fruit grown in tropical regions is considered a fast-growing perennial crop that can be harvested year-round. Its production is essential to the economies of many developing countries. As a staple food, bananas contribute to food security and given their sales in local markets, provide income and employment and as an export commodity contribute to the economies of many countries [9,14]. Worldwide, 113,212,452 tons of bananas are produced per year. India is the largest banana producer in the world with a production volume of 29,124,000 tons per year, China ranks second with an annual output of 13,324,337 tons [14]. As indicated in the canary statistics, from the Agriculture and Fisheries Department of the Government of the Canary Islands [15], the total agricultural generation for the Canary Islands meant a production of 918,037.60 tons for the year 2020, with Banana productions standing out with 420,144.10 tons, which represents 45.77 % of the total, followed by Potatoes with 7,8150.7 tons, which represents 8.51 % of the total, and Tomatoes with 65,389.90 tons, which represents 7.12 % of the total. Almost 50 % of the agricultural production of the Canary Islands in 2020 was based on bananas, (Annex, Table 26), which leads to a high production of agricultural residues in banana production, specifically for the year 2020, it turned out to be 36,765.3 tons, which represents 8.75 % of the marketed production. The Canary Islands are one of the world's largest producers of bananas, and of the Musa Acuminata Colla (AAA) species, Cavendish variety (Fig. 1). In 2021, there was a cultivation area of 8,666 ha in which approximately 412,000 tonnes of bananas were produced per year, which are conditioned and packaged in 95 packing centres located in the Canary Islands [15]. Around 90 % of this production is transported to the Peninsula where they undergo a forced maturation process prior to marketing, with an average production in the last 5 years, 2017 to 2021, of 415,337.32 tons per year used for export worldwide. Of this annual production there is a percentage of bananas that is not marketed and that can be subject to their valorization, specifically it is an average in recent years, from 2017 to 2021, of approximately 30,000.00 tons/year. This waste of the Canary Islands banana can and should be studied for its recovery as a biofuel [12]. This would lead directly to a reduction in discharges and transports of discharges and, therefore, consequently, a reduction in the carbon footprint (see Tables 1–2).

With the valorization of banana waste, and taking advantage of its potential in sugar, several objectives can be promoted [16]:

a) From its commercialization as such.
b) Its transformation into bioethanol.
c) The transformation of bioethanol into MEA (monoethanol amine) for commercialization.
d) The use of MEA for CO_2 capture.
e) And even CO_2 capture and production of synthetic fuels, net CO_2 emissions, net zero tCO_{2eq}, efuel.

Table 1
Canary Island Banana and American Banana. Emissions per kg of product.

	Banana from the Canary Islands (Muse Sharp Glue)	Banana America(Musa cavendish,..)
CO_2 emission	195.00 g	1000.00 g

Source: [26].

Table 2
Canary Island Banana and American Banana. Organoleptic comparison per kg of product.

	Canary Island Banana (Musa acuminata colla)	Banana Americana (Musa cavendish,..)
Carbohydrates	22.40 g	26.20 g
Starch	8.50 g	18.00 g
Total Sugars	14.10 g	8.40 g

Source: [24].

Of all this, its transformation into bioethanol represents the most applicable renewable biofuel [17] with more applicable [18], in disposable aspects such as transportation [19] between biological processes such as anaerobic digestion (AD), fermentation [20], among others as a basis for the generation of biofuel [21] from waste [22,23].

Specifically, this article proposes to estimate the potential of transformation of the existing sugars in the waste of the Canarian banana to transform it into a 100 % renewable fuel, bioethanol, and it is also proposed to study because of the production of bioethanol, the environmental impact that its new carbon footprint has on banana production. The novel aspect is based on the inventory and potential for conversion of the discarded fruit part and its use into biofuel [16,18] Unlike other studies such as [13,19,20,22] which focus on the woody part of the plant and, because of this valorization, the reduction of the carbon footprint of the cultivation and marketing of the Canarian banana. The ethanol obtained would be a renewable fuel of biological origin, from sugary or starchy substances, bioethanol, and also complies, as it cannot be otherwise, with the regulations on this type of renewable fuels: the speed of consumption is comparable to the speed of production, there is no depletion, since it is produced continuously, the CO_2 emitted into the atmosphere by combustion was captured from it in a nearby previous period, so there are no net CO_2 emissions contributing to the mitigation of the carbon footprint.

Fig. 1. Canary island banana fruit plantation.

2. Materials and methods

2.1. Methodology

The conditions for ensuring the renewability of renewable fuels are:

a) Energy balance: Do not consume non-renewable energy for its production.
b) Environmental balance: Do not generate more emissions than are avoided, nor other impacts (soil, biodiversity, etc.).
c) Economic balance: Production costs must be comparable to those of conventional ones, at least in the long term.

To this end, the following parts of the process are identified (Fig. 2):

a) Modelling of the Canarian banana, where all the variables that affect the Canarian banana are established and the variables that directly influence this valuation are studied, the species and characteristics of the Canarian banana, where the banana is physically characterised, the parts of the fruit, percentage by weight, where the parts of the fruit that are recoverable are differentiated, the time of use of the banana fruit, where the time of recovery is characterized and the sugar content is examined, the sugar content and type are characterized,
b) Context of the Canary Islands banana production, estimation of the tonnes of bananas potentially recoverable, in this section a study of the annual productions of recent years is made and the starting units for the calculation of the recovery are established.
c) Estimation of the potential tonnes of sugar that can be obtained by the valorisation of the Canarian banana.
d) Bioethanol from Canarian bananas, where the annual production of bioethanol from banana waste is estimated,
e) Energy and environmental impact of bioethanol produced from bananas in the Canary Islands, where the reduction in fossil fuel consumption in the automotive industry due to the inclusion of bioethanol in automotive fuels, E10 gasoline, and its environmental impact in the Canary Islands, is once again estimated,
f) Carbon footprint, where the new carbon footprint is studied with and without recovery.

2.2. Modelling of the Canarian banana

In this section, the variables for the modelling of the Canarian banana are studied and defined. These variables (Fig. 3) define and characterize the cultivated banana, its characteristics, the production process, its economic performance and its influence on the environment. They affect the type of species and the characteristics of the Canarian banana, differentiate the parts of this fruit due to their different sugar contents, establish and differentiate the time of use of the banana fruit, since depending on this time variable, the sugar contents vary, and determine the sugar contents and types. These variables also have an impact on banana production and its productive and economic performance. Some variables can be controlled to some extent, such as the variables that define physical characteristics, the variables that characterize production, marketing and distribution, production and the impact on the environment. Other variables are more difficult to control, but they have an expected inertia and evolution known in advance, such as market prices and expected revenues from marketing. These variables would be:

2.2.1. Species and characteristics of the Canarian banana

The Canarian banana (Musa acuminata Colla AAA, Cavendish variety) and the banana (Musa cavendish and its various varieties) are almost the same fruit which, depending on the place, takes different names but with differences in composition (Fig. 4) [24,25]. These characteristics are shown in the following figures and tables:

2.2.2. Parts of the fruit, percentage by weight

Banana fruit must be distinguished and differentiated between two parts, the edible part of the banana, the banana pulp (P) and the banana peel (C). Such differentiation is important as their sugar content is different.

As referenced [25], as well as [27], banana peel is a valuable source of bioactive compounds and makes up between 30 % and 40 % of a banana fruit, so our goal is to valorize the edible part of the banana and its peel. This data was corroborated by laboratory experimentation. In more than 60 samples weighed in the laboratory, an average of 36 % was obtained. But as will be seen in later sections, given the little difference in sugar content between the two parts of the fruit, this data is not so relevant.

2.2.3. Moment of valorization of banana fruit (CP)

It is also necessary to distinguish and differentiate the sugar composition of bananas at the time of marketing, which is different from that of the time of possible recovery of the banana.

The first stage of ripening shows a banana with a green color that betrays that it is not ripe and, therefore, has little sugar. In this state, bananas are loaded with starch. A green banana has a lower glycemic index.
The second phase of ripening of the fruit shows a color that betrays that the banana is underripe, in this phase it has a high fiber content and little sugar. It has a higher glycemic index, has less starch to break down.

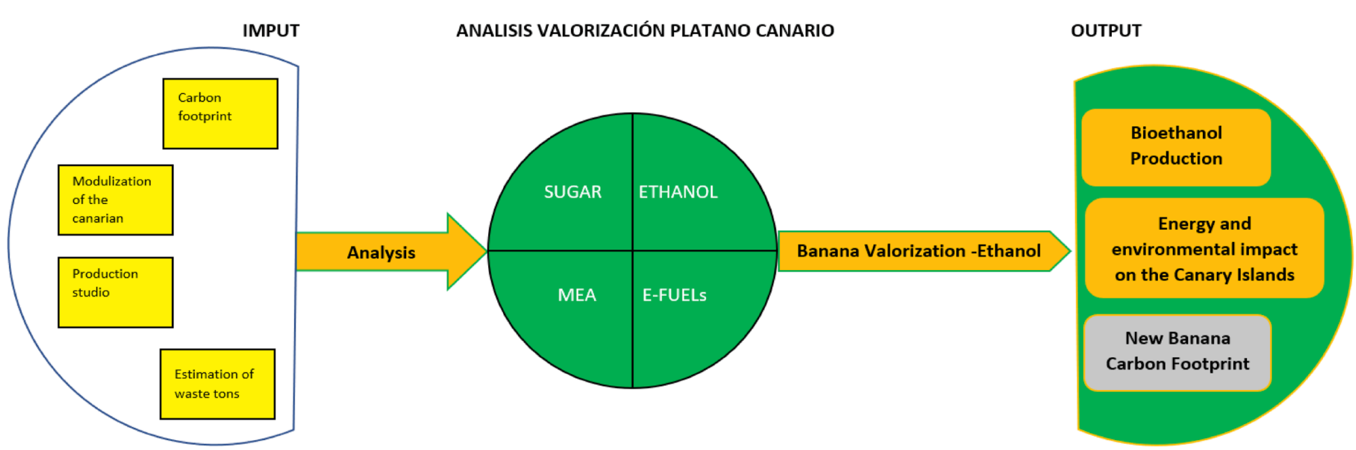

Fig. 2. Methodology.

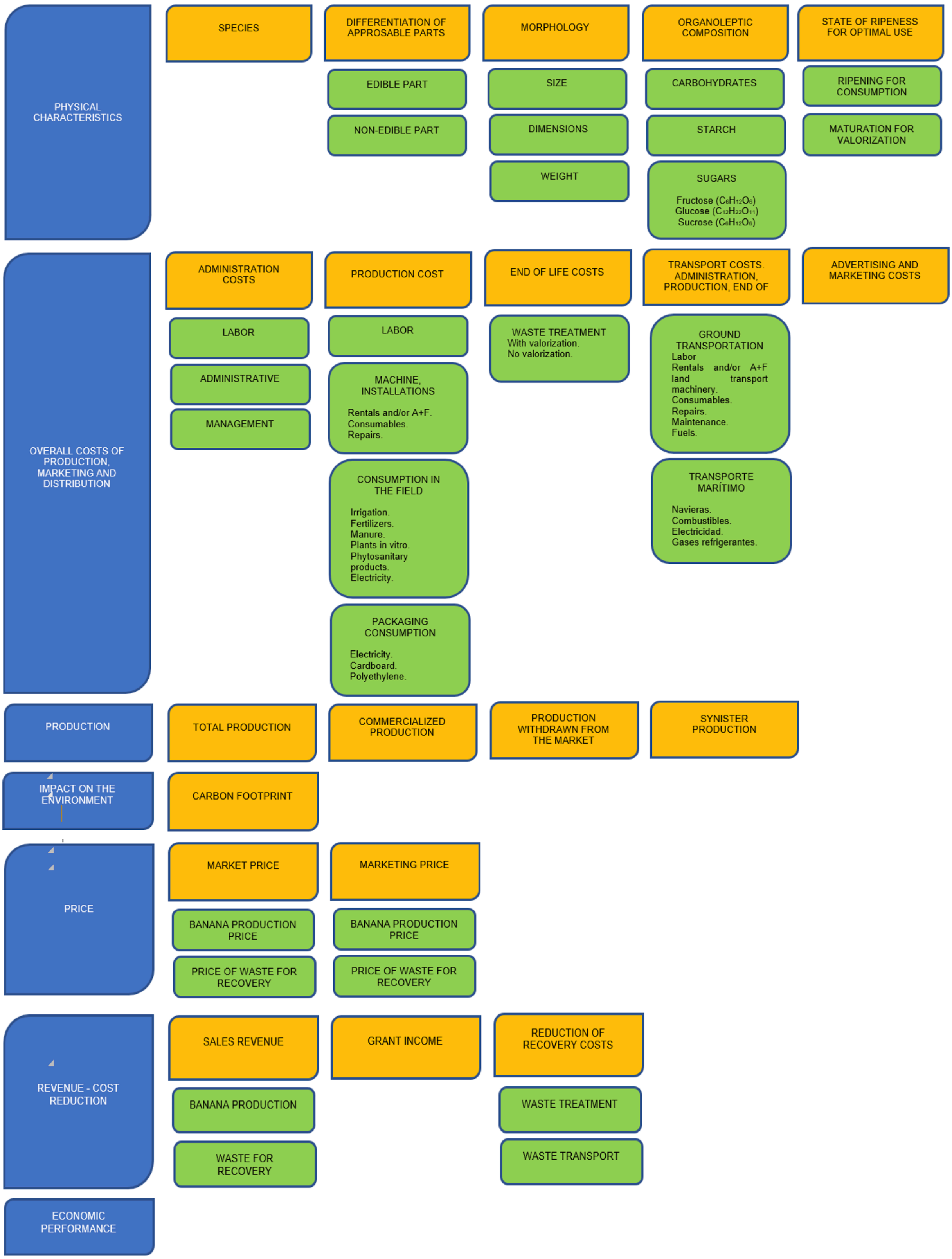

Fig. 3. Variables for modelling.

In the third phase, the banana is ripe, which can be considered optimal for consumption, but not for recovery. It shows a yellow color with no brown spots and is characterized by a higher antioxidant load and a good fiber content.

In the fourth phase, it is a very ripe banana, which is characterized by several brown spots. In this phase, the sugar content of the fruit increases in parallel with the number of brown spots.

In the last phase, a banana appears completely brown, i.e. it is overripe. In this phase, the fruit has the highest sugar and fiber

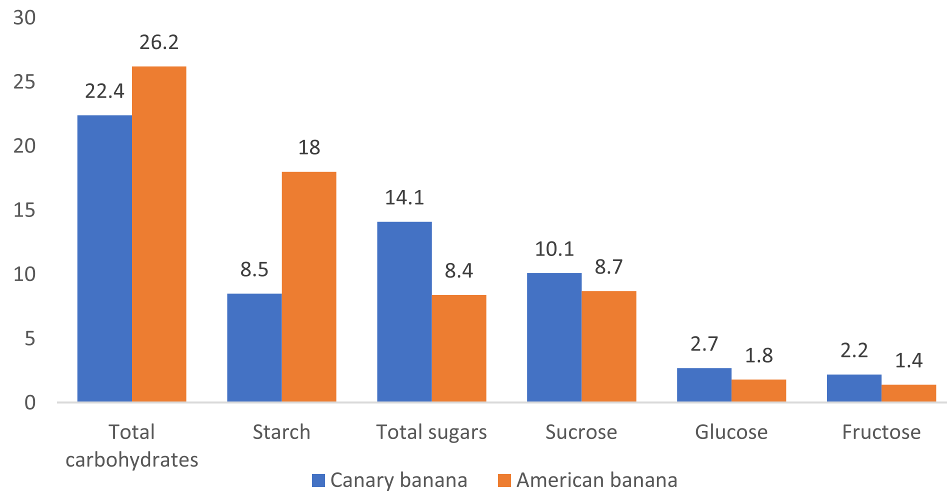

Fig. 4. g/100 g edible portion [24].

content. The starch has been converted to sugar and the chlorophyll has been broken down due to the deterioration of the chloroplasts, causing the level of antioxidants to increase significantly. This is the optimal phase for its valorization.

2.2.4. Sugar content

At this point, it is a question of quantifying the global sugar producing potential of bananas, fruits and peels at the time of recovery.

2.2.4.1. Regarding the pulp of the banana (P). The Canarian banana (Musa Acuminata Colla, Cavendish variety) has a composition high in sugars and starches. This makes it attractive to use for sugar production or fermentation. The detailed carbohydrate composition of the Canarian banana, grams per 100 g of banana, determined by the Luff-Schrool volumetry method, is as shown below (17.83 %):

This analysis of the composition of the banana carried out by Asprocan is at the optimal time of marketing and consumption, this sugar content is different from the sugar content at the time of valorization, i.e. ripe banana. That study is shown below.

As referenced in [29], The average composition of ripe bananas includes NSP, which can be divided into water-soluble (1.07 g/100 g) and insoluble (1.68 g/100 g) polysaccharides, starch (3.47 g/100 g), soluble sugars (sucrose, 15.20 g/100 g, glucose, 2.34 g/100 g, fructose, 1.98 g/100 g) and water (70.93 g/100 g), also referenced in the [30]. The soluble sugar fraction in ripe bananas is appreciable, representing more than 19 % of the total fruit mass (19.52 %):

2.2.4.2. As for the banana peel (C). Banana peel accounts for between 30 % and 40 % of the weight of bananas, 35 % by weight on average of the overall banana fruit. There are different possible processes for an extraction of sugars from banana peel, by dilution in water with previous crushing of the banana peel 0.2 g of sugar is obtained for each gram of processed banana peel and the total sugars obtained was 6.1252 g/L of dilution, similar tests have been carried out and published [30], The sugar composition obtained for banana peels is close to 20 % (19.99 %):

2.3. Context of Canarian banana production, estimation of the tons of potentially recoverable bananas

As mentioned above, the Canary Islands are one of the world's greatest powers in the production of bananas, specifically the banana fruit of the Musa Acuminata Colla species, Cavendish variety. With a high volume of banana production in the Canary Islands, in the last three years this has been 430,023,156 kg in 2020, 411,732,930 kg in 2021 and 349,094,225 kg in 2022. As can be seen, the production of the year 2022 has been dragging the consequences of the pandemic that has a belated impact on the crops and their productions. Therefore, it is not a characteristic reference year. Due to the high production volumes of Canarian bananas, large quantities of non-marketed bananas have been generated. They are the bananas that have been damaged and the bananas that have been recalled. Bananas are not included in this quantification of production, as this quantification does not take into account damaged units, or discarded units, as is evident. The production of bananas is inevitably accompanied by the generation of large quantities of banana waste (damaged bananas), this is basically due to overripening, damage to the product, etc., in short, due to non-compliance with the minimum quality requirements required for its commercialization. They are divided into two categories, the extra category and the first category. These requirements are for the extra category:

And for the first category the requirements are:

Bananas withdrawn from the market are included in this quantification, this cause is due to the fact that, even if they meet the minimum quality requirements, they are not marketed due to various interests such as price adjustment, low profitability, etc., playing with the tons placed on the market to obtain the best return.

The following tables show the production of bananas by islands, the quantities damaged and the quantities withdrawn from the market.

All this means that the sum of the tonnes of bananas damaged and the bananas withdrawn from the market is:

What it means as a percentage of the actual production (production that was actually marketed):

All this indicates that the annual average from 2017 to 2021 of tonnes of bananas damaged and withdrawn from the market is about 30,000 tonnes of bananas per year. This will be our working figure: 30,000 tonnes of bananas per year, which represents 7.34 % of net production, i.e. the production actually marketed.

2.4. Estimation of the potential tonnes of sugar that can be obtained by the valorisation of the Canary Islands banana

Unifying the data on the peel and pulp of the banana of this species in its optimum state of ripeness for valorization and for a working figure of 30,000 tons of bananas per year, the potential sugars that can be obtained from the banana peel and the edible fruit are:

Therefore, the potential banana sugar producer for a working figure of 30,000 tonnes of bananas per year is set at 5,906.40 tonnes of sugar per year (see Figs. 5–6).

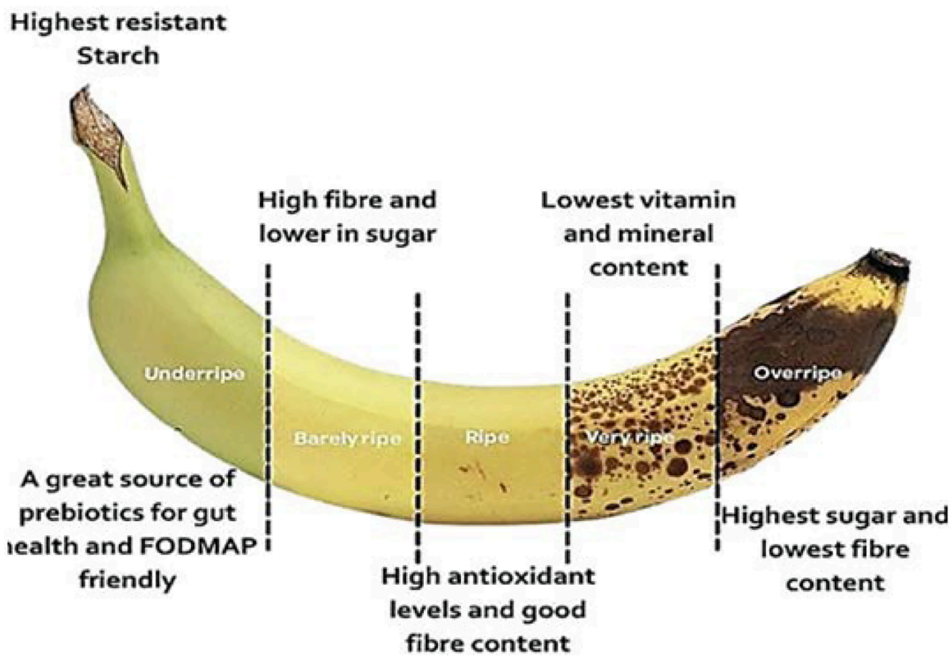

Fig. 5. Maturation stages [26].

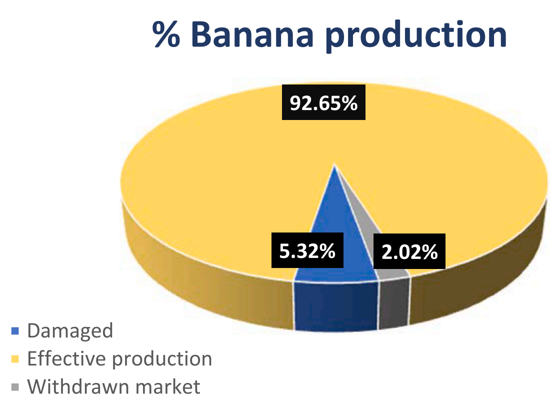

Fig. 6. Distribution of banana production according to use [26,28].

2.5. *Biothanol from the Canarian plátano*

2.5.1. *Energy alternatives from bananas*

The possible results that may result from the valorisation of non-marketed banana fruit vary, from the most immediate, such as obtaining sugar, to more complex ones such as obtaining by-products from bananas or their sugars, such as ethanol, MEA, etc., or even the production of energy [31,32]:

- Sugar marketing.
- Transformation of banana waste into ethanol. This ethanol production could be used as a fuel that would help decrease the use of fossil fuels, or their commercialization for different uses.
- Transformation of ethanol into MEA (mono ethanol amine) for commercialization.
- Use of MEA for CO_2 capture.
- CO_2 capture and production of synthetic fuels, net zero CO_2 emissions, e-fuels.

2.5.2. *Bioethanol*

In 2019, 50 % of the ethanol produced was corn, followed by wheat (25 %) and sugar (14 %).

99 % of the bioethanol manufactured in Europe has been made with raw materials grown in Europe As already mentioned, Bioethanol is a renewable fuel produced from waste or sustainable crops, provides undoubted environmental improvements and contributes to the development of the rural economy. Its physico-chemical characteristics make bioethanol the ideal fuel to replace gasoline in Otto cycle engines [33].

a) It does not require a breakthrough technology, it is a real alternative that is easy to implement and profitable for the user.
b) There is no need for investment in new supply infrastructure and the starting point is the engine technology that exists today.
c) It contributes to energy diversification, the environment and the economic development of the country (agricultural and industrial).
d) It decreases fossil fuel imports and helps prevent rural depopulation.

2.5.3. *Bioethanol used as fuel*

2.5.3.1. Bioethanol B-10. Fuel with an ethanol concentration of 10 %. Bioethanol, in addition to being a renewable fuel, is very efficient in combustion engines. This increase in efficiency and better combustion reduces consumption, but also helps to improve harmful emissions. Just by going from E5 to E10, NOx is reduced by 34 %, particulate matter by more than 90 % and hydrocarbons by 60 %, with E85 the improvements would be greater. The more ethanol that is blended with gasoline, the greater the benefits. Commercially available gasoline vehicles built after 2000 can run on a blend of gasoline and bioethanol up to 10 %, also known as E10 gasoline. The E10 can be used in approximately 90 % of all petrol cars in the current fleet.

2.5.3.2. Bioethanol B-85. Fuel with an ethanol concentration of 85 %. Bioethanol can also be used in higher concentrations. A blend of 85 % ethanol and the rest gasoline, called E85, is widely available in Sweden, France, Germany, and more sporadically in Hungary, Austria, the Netherlands, and Spain. The E85 reduces emissions of CO_2, CO, particulate matter and provides significant reductions in emissions of many harmful toxicants, including benzene, a known human carcinogen. E85 requires "flex-fuel vehicles" (FFVs), which can run on E85, gasoline, or any mixture of both, without the need for separate fuel tanks. In 2003, Brazil was the first to introduce FFV, and today they account for more than 90 % of new car sales in that country. Converting a current gas-powered car to an FFV car is simple and economical. Unfortunately, Europe is lagging behind and must significantly improve its infrastructure to enable further deployment of the E85.

2.6. Carbon footprint of the Canarian plantain

The product's carbon footprint is the total amount of greenhouse gas (GHG) emissions generated in each of the phases of the product's life cycle (from the extraction of the raw materials that compose it to the destination to the abandonment of the product). There are currently various standards, references and guides for the calculation of the Carbon Footprint of products, both general and sectoral, promoted by various public or private institutions of recognized prestige. For example, PAS 2050, GHG Protocol, ISO 14067, International Wine Protocol, etc.

Product/service verifications for the measurement of the Carbon Footprint can be of four types:

a) Calculated CO_2: certifies the veracity of the calculation of the Carbon Footprint of a product/service, i.e. the set of Greenhouse Gas (GHG) emissions generated by a product/service throughout its life cycle.
b) Reduced CO_2: the organization has to demonstrate that its product/service has been reduced compared to the previous year and its right to use is granted annually.
c) CO_2 Offset: In this case, the offset emissions in pollution sinks are calculated, which will be subtracted from those calculated in the product/service carbon footprint.
d) Carbon Neutral: the carbon footprint is calculated with internationally recognised benchmarks, and following the hierarchical order, an Emissions Reduction Plan is carried out, and residual emissions are offset through recognised compensation mechanisms. In this case, the current reference is the PAS 2060:2014 Standard (ISO standard under development).

2.6.1. Calculation of the carbon footprint of bananas

The purpose of this study is to show the calculation of the CO_2 emissions of 1 kg of Canary Island Bananas. Differentiated whether or not there has been valorization in a part of the production that is not marketed and that is not exported to the Peninsula. The aim is to differentiate the recovery of the damaged banana and the banana withdrawn from the market in the carbon footprint of the banana. And, as indicated, approximately 30,000 tons of bananas (7.34 % of net production) are withdrawn from the market, 21,671.45 tons due to claims and 8,239.70 tons due to market needs. By valorizing them and taking them out of the chain, out of the life cycle, it has an impact on the carbon footprint in two different ways:

a) In the case of the damaged banana, it has an impact on the life cycle from the moment its evolution in the cycle is interrupted by declaring a loss. Normally, it is declared a loss when it does not pass the first quality controls, i.e. in the early stages, mostly in the field and packaging.
b) In the case of bananas withdrawn from the market due to the needs of that market, it has an impact on the life cycle from the moment its evolution in the cycle is interrupted, forced by the needs of the market, this normally happens with bananas in their intermediate stages, packaging and distribution and ripening mostly.

The table below shows the total productions and the percentage impact.

With all this, the total production of bananas, including those damaged and withdrawn from the market, Total Production (3), is 437,008.37 tons per year on average, from 2017 to 2021, and as already indicated, the quantities of bananas damaged 21,671.45 tons per year on average, from 2017 to 2021 and bananas withdrawn from the market 8,239.70 tons per year on average, from 2017 to 2021. This represents 4.96 % and 1.89 % of total production respectively. If these percentages are analysed on net production, Total Production (2), That is, the one that really comes out badly in the market, 407,097.62 tons per year on average, from 2017 to 2021, the percentages of quantities of bananas damaged and bananas withdrawn from the market represent 5.32 % and 2.02 % of the total net production respectively.

2.6.2. Overview & scope

2.6.2.1. Purpose of the study. The purpose of this study is to show the calculation of the CO_2 emissions of 1 kg of Bananas from the Canary Islands for export to the Peninsula (financial year 2021) and its modification taking into account the valorization of the banana that is analyzed here. The calculation of the carbon footprint has been carried out following the standard for the quantification and reporting of the life cycle of products developed by the experts of the GHG Protocol. Following this standard, firstly, the functional unit of reference for the study is defined, as well as the limits and scope of the system. The activity data for each of the stages and the corresponding emission factors are then collected, and the inventory of GHG emissions is carried out.

2.6.2.2. Definition of the product studied. The Canary Island Banana is the fruit of the Musa acuminata Colla (AAA) species, Cavendish variety, grown in the Canary Islands Archipelago and intended for fresh consumption. In 2021, there was a cultivation area of 8,666 ha in which approximately 412,000 tonnes of bananas were produced per year, which are conditioned and packaged in 95 packing centres located in the Canary Islands. Around 90 % of this production is transported to the Iberian Peninsula where it undergoes a forced maturation process prior to being marketed.

2.6.2.3. Definition of the functional unit. As a functional unit for calculating the carbon footprint, 1 kg of Canary Island bananas exported to the Peninsula for fresh consumption is taken. The reference flow is the volume of bananas marketed in the year under study, of which approximately 90.7 % were marketed on the mainland market.

2.6.2.4. Inventory type. The cradle-to-grave inventory accounts for emissions from the sourcing of raw materials and the manufacture of the inputs used to the waste management of the product under study.

2.6.2.5. Inventory date and version. This study corresponds to version 4.0 of the GHG inventory of the Canary Islands Banana prepared during the year 2022 for the financial year 2021 [26].

2.6.2.6. Methodological changes compared to other versions. In the third version of the GHG inventory of the Canary Islands Banana (prepared in 2018 for the 2016 financial year) we worked with primary and secondary activity data, as well as with assumptions or estimates by experts. In this fourth version, we have sought to work with a greater number of primary data, also increasing the sample size to obtain more representative mean values. In this version, the emission factor of the electricity mix of the marketers provided by the Ministry of Ecological Transition and Demographic Challenge has been taken, as it is considered to be more real than the emissions to the generation provided by Red Eléctrica used in previous versions.

2.6.3. System limits

2.6.3.1. Life cycle. The cultivation of the Canary Islands Banana has a production process that consists of the following phases that can be grouped into four stages:

Field stage: Fertilization phases, Irrigation, Tillage, Transport to packaging.
Packaging Stage: Processing and packaging phase.
Distribution and maturation stage: Phase of land transport to port of departure on the islands, Sea transport to the peninsula, Land transport on the peninsula, Maturation.
Use and end of life: Consumption phase, Transport, Waste management.

The emissions of each of the stages of the life cycle of the Canary Islands Banana are as follows:

- Field stage: Emissions from the manufacture and transport of inputs, Energy consumption: electricity and fuels used for the operation of tillage equipment, irrigation, irrigation water treatment and desalination, Soil emissions from the application of fertilizers, Fuel consumption of vehicles during transport to packaging.
- Packaging stage: Electrical energy consumption for the operation of equipment and cold rooms, Emissions from the manufacture and transportation of packaging materials.
- Distribution and maturation stage: Replenishment of refrigerant gases from refrigerated containers during transport to the mainland market (packaging-final market), Emissions during maturation (ethylene and energy consumption), Fuel consumption of vehicles during transport to the mainland market: by land, from packaging to port, by sea, from port in the Canary Islands to mainland port and by land, from mainland port to distribution centres.
- Use and end-of-life: Fuel consumption of vehicles during the transport of waste to the manager, Emissions during the end-of-life of product waste.

2.6.3.2. Field map. Process map of the life cycle of Canary Islands bananas without valorization. It is shown in Fig. 7, Process map of the life cycle of the Canary Islands Banana without considering valorization:

Exclusions. The processes that have been excluded from the inventory are as follows:

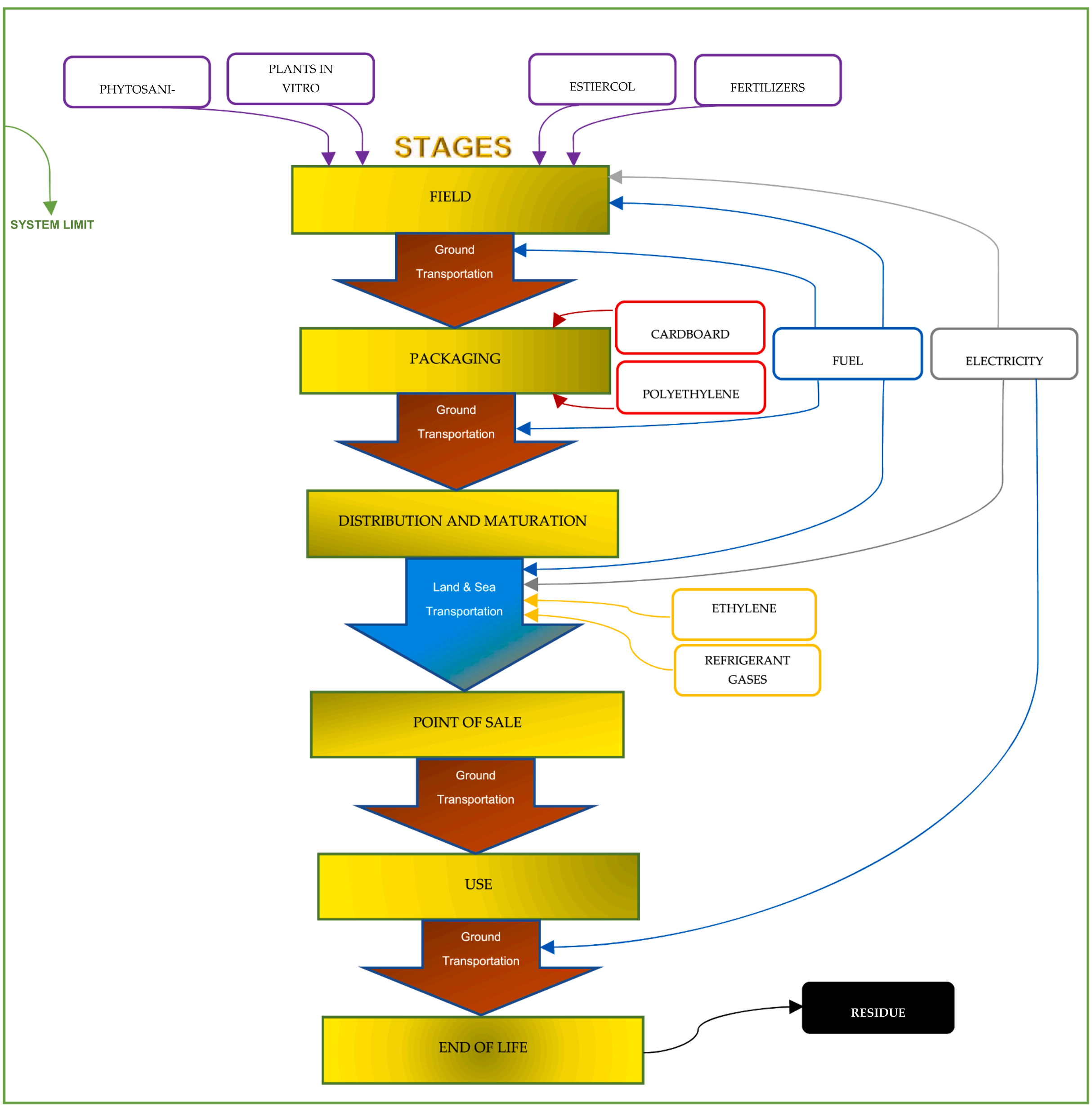

Fig. 7. Process map of the life cycle of Canary Islands Bananas without Valorization.

- Processes not attributable to the product: those that are not directly linked to the product studied during its life cycle, either because they are not part of it or transport it directly, as in our case is the transport of employees to the workplace, capital goods or the transport of buyers to the point of sale.
- Processes whose emissions are considered insignificant because they involve emissions of less than 1 % of the calculated footprint:

Change of land use: This type of emissions has not been included since most of the farms exceed 20 years since they were planted.

Use of the product: due to the high level of uncertainty of this stage and the fact that its estimated emissions are considered non-significant, as it is a fruit that does not require refrigeration.

Transport of phytosanitary products, bags and hand separator paper: these have been excluded from the inventory due to the difficulty of obtaining reliable data, since the place of manufacture can be highly variable, even for the same company and product, and the low level of use of these products gives them little significance within the total emissions of the product.

Long-life field inputs: Inputs with a useful life of more than 25 years have not been considered as windbreak nets as their estimated emissions are considered non-significant.

Diesel expenditure in emergency facilities: the diesel spent on emergency generators present in the packaging facilities has not been considered in the inventory due to its very punctual use, which means that the emissions are not significant.

Refrigerant gas leaks in ripening facilities: these have not been considered due to the difficulty of obtaining reliable data, however, it is considered that for future updates more information may be available and can be included.

Time period. The activity data used for the calculation of the carbon footprint corresponds to the year 2021.

2.6.3.3. Data sources. For the calculation of CO2 emissions, activity data and emission factors were taken for each process, and the activity data was multiplied by their corresponding emission factor. Primary and secondary activity data taken from the results of surveys conducted in all areas were mainly used. In cases where such data could not be obtained, assumptions and estimates were used by experts. In the case of processes external to the sector, the data was requested from the providers of each service, i.e. from the owners of the process. Such is the case of ripeners and shipping companies, among others. Particular emphasis has been placed on the field and packaging phases in order to obtain data that is representative of the entire sector. To ensure this representativeness, the main productive islands have been divided into geographical zones within which the cultivation conditions are considered to be homogeneous.

Field surveys. A total of 93 surveys have been carried out with producers to obtain the main parameters associated with the crop. To ensure representativeness, there are 52 surveys in Tenerife, 17 in Gran Canaria and 24 in La Palma, distributed in the different producing areas and covering the different irrigation systems used (drip, sprinkler) and farms of various sizes (from 1,940 to 260,000 m2).

Packaging Surveys. To obtain the data on packaging, surveys were carried out in 10 centres (10.53 % of the total) that represent more than 19 % of the total production, located on the following islands (4 in Tenerife, 2 in Gran Canaria and 4 in La Palma). In this way, it is ensured that the various circumstances that may condition the activity and, therefore, the emissions inventory are covered.

Surveys of ripeners. To obtain the packaging data, surveys were carried out at 10 ripening centers (10 % of the total in the Peninsula) distributed throughout the peninsular geography.

2.6.3.4. Carbon fixation. Carbon fixation is the conversion of inorganic carbon (in the form of carbon dioxide) into organic compounds by living things. The most important example of carbon fixation takes place in photosynthesis during the dark phase, although chemosynthesis is another form of carbon fixation that occurs in the absence of light. Organisms that grow by fixing carbon are called autotrophs. Autotrophs include photoautotrophs, which synthesize organic compounds using light energy, and lithoautotrophs, which synthesize organic compounds using the energy produced by inorganic oxidations. Heterotrophs are organisms that grow using carbon that was fixed in organic compounds by autotrophs. Heterotrophs use organic compounds to produce energy and to build body structures. The terms "fixed carbon," "reduced carbon," and "organic carbon" are equivalent for several organic compounds.1 The same influence of the sun's rays is highlighted in natural respiratory terms. It is estimated that photosynthesis converts approximately 258 billion tons of carbon dioxide each year. Most fixation occurs in the oceans, especially in nutrient-rich areas with an abundance of phytoplankton. The gross amount of carbon dioxide fixed is much higher as approximately 40 % of the total fixed is consumed in the respiration on a daily basis. The carbon-fixing enzyme RuBisCO is considered to be the most abundant protein on Earth. Until 2011, six autotrophic carbon fixation pathways were known: the Calvin cycle, which fixes carbon in the chloroplasts of plants and algae and in cyanobacteria. Carbon is also fixed in anoxygenic photosynthesis by a group of proteobacteria called purple bacteria, and in some non-phototrophic proteobacteria.

For the case that is being worked on here, the carbon fixation produced by the banana fruit in its formation per kg of banana is 154.65 gCO_2/kg.

2.6.3.5. Summary and analysis. Summary and analysis of the carbon footprint of bananas from the Canary Islands. (gCO_2/kg produced) without valorization. Table 19, Fig. 8 and Fig. 9 show the summary results and analysis of the carbon footprint of the Canary Islands banana (gCO_2/kg produced) without Valorization.

The analysis of the inventory of the emissions generated makes it possible to identify the processes that generate the highest amount of GHGs. To this end, the emissions generated at each stage have been studied, the most significant being the distribution and ripening, which accounts for 40.39 % of the total (111.23 gCO_2/kg banana). The field stage is the second most important with the generation of 28.47 % of emissions (78.39 gCO_2/kg banana), followed by the packaging stage with 21.27 % (58.57gCO_2/kg banana) and finally the end-of-life stage which represents 9.87 % of GHG emissions (27.17 gCO_2/kg banana) (see Tables 3–18).

The processes whose emissions have the greatest weight on the carbon footprint of the Canary Islands Banana are the transport of the fruit to the market (fuel emissions), which account for 33 % of them, the manufacture and transport of packaging materials (18.5 %), the application of nitrogen fertilisers (14.0 % of emissions), and the manufacture and end of life of the product (9.2 %) (see Tables 20–23).

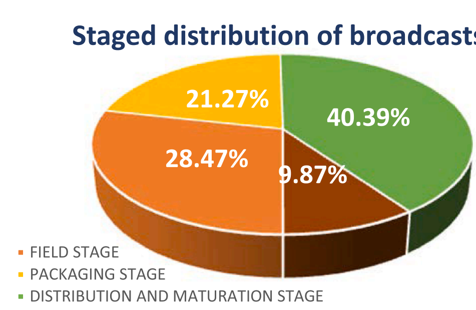

Fig. 8. Distribution of Emissions by stage. .
Source: [26]

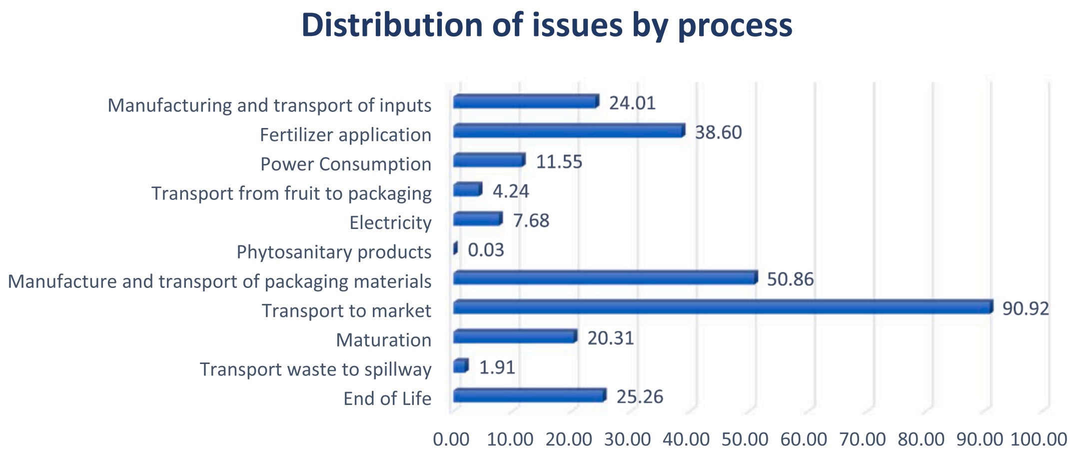

Fig. 9. Distribution of emissions by process. .
Source: [26]

Table 3
Canary Island Banana and American Banana. Morphological differences.

	Canary Island Banana (Musa acuminata colla)	Banana Americana (Musa Cavendish, etc.)
Weight	237.60 g	135.50 g
Long	15.70 cm	20.50 cm
Diameter	38.00 mm	39.00 mm
Weight/ Long	15.14 g/cm	6.61 g/cm

Source: [24].

Table 4
Commercial banana pulp. Carbohydrates (g/100 g of banana).

	%	g/100 g
Total Sugars	–	17.83
Fructose ($C_6H_{12}O_6$)	37.02 %	6.60
Glucose ($C_{12}H_{22}O_{11}$)	37.41 %	6.67
Sucrose ($C_6H_{12}O_6$)	12.90 %	2.30

Source: [28].

Table 5
Valorizable banana pulp. Carbohydrates (g/100 g of banana).

	%	g/100 g
Total Sugars	100.00 %	19.52
Fructose ($C_6H_{12}O_6$)	10.14 %	1.980
Glucose ($C_{12}H_{22}O_{11}$)	11.99 %	2.340
Sucrose ($C_6H_{12}O_6$)	77.87 %	15.20

Source: [29].

Table 6
Recoverable banana peel. Carbohydrates (g/100 g of banana peel).

	%	g/100 g
Total Sugars	–	19.99
Fructose ($C_6H_{12}O_6$)	32.41 %	6.327
Glucose ($C_{12}H_{22}O_{11}$)	37.01 %	7.224
Sucrose ($C_6H_{12}O_6$)	32.99 %	6.439

Source: [30].

Table 7
Characteristics of the EXTRA category.

Presentation		Bunches
Net weight		9 kg/18 kg
Characteristics of the fruit	Common Requirements:	Green bananas, whole, consistent, healthy and clean (without wounds, foreign matter or rot).
	Specific requirements:	The fingers should not have defects, except for very slight superficial alterations that do not exceed the total of 1 cm2 of the surface of the finger.
	Tolerance:	5 % in number or weight of bananas that do not meet the calibration of the category.
Templates	Thickness (mm):	Minimum 32
	Longened (mm):	Minimum 140
Packaged.		Box 60X40X14.5 cm with micro-perforated bag

Source: [15].

Table 8
Characteristics of commercialization category FIRST.

Presentation		Bunches
Net weight		18 kg
Characteristics of the fruit	Common Requirements:	Green bananas, whole, consistent, healthy and clean (without wounds, foreign matter or rot).
	Specific requirements:	The fingers must not have defects, except for very slight superficial alterations that do not exceed the total of 2 cm2 of the surface of the finger.
	Tolerance:	10 % in number or weight of bananas that do not respond to the calibration of the category.
Templates	Thickness (mm):	Minimum 28
	Longed (mm):	Minimum 140
Packaged		Box 60X40X24.5 cm with micro-perforated bag

Source: [15].

3. Results and discussion

3.1. Bioethanol

3.1.1. Estimation of bioethanol production. Impact on the Canary Islands energy market

As stated [34] for an estimated production of 30,000.00 tonnes of bananas/year destined for recovery and proposing the use of a

Table 9
Banana production by islands and year (ton).

Islands	2016	2017	2018	2019	2020	2021	2022
Tenerife	184,391.1	186,950.3	162,245.2	170,354.0	182,532.9	186,564.0	175,625.2
La Palma	151,327.4	151,512.7	143,592.0	141,794.3	148,658.2	131,962.7	77,104.0
Gran Canaria	88,837.1	90,349.0	77,253.2	85,754.8	9,346.4	85,484.0	89,262.2
La Gomera	5,788.0	5,710.3	4,672.6	5,186.7	5,245.3	4,698.0	4,061.1
El Hierro	3,197.4	3,123.7	3,008.9	2,967.4	3,076.0	2,824.6	2,814.1
Fuerteventura	–	–	48.0	67.6	76.6	90.3	110.5
Lanzarote	137.3	136.0	104.8	100.0	87.8	108.3	117.1
Total	433,678.2	437,782.1	390,924.6	406,224.8	430,023.2	411,731.9	349,094.2

Source: [15].

Table 10
Bananas damaged by islands and year (ton).

Islands	2016	2017	2018	2019	2020	2021	2022
Tenerife	729.7	3,543.5	10,171.3	14,312.3	15,988.4	1,621.4	5,332.5
La Palma	916.1	5,803.8	6,485.2	6,734.8	9,104.1	23,206.0	1,808.1
Gran Canaria	1.3	1,715.4	2,319.5	52.8	662.7	504.1	438.1
La Gomera	370.9	1,196.1	1,413.0	1,722.1	1,089.7	246.3	993.4
El Hierro	38.8	138.0	60.3	205.3	41.3	16.0	67.8
Fuerteventura	–	–	–	–	–	–	–
Lanzarote	–	–	–	–	–	–	–
Total	2,056.8	12,396.7	20,449.3	23,027.2	26,886.2	25,597.9	8,639.9

Source: [15].

Table 11
Bananas recalled by islands and year (ton).

Islands	2016	2017	2018	2019	2020	2021	2022
Tenerife	6,302.9	6,770.3	2,430.6	2,579.4	4,932.1	665.3	1,018.6
La Palma	6,360.2	6,404.4	1,412.5	3,343.6	3,031.7	1,639.9	434.8
Gran Canaria	3,129.6	2,915.4	756.7	1,407.3	1,648.4	292.3	220.3
La Gomera	248.9	289.4	72.9	126.2	177.3	18.2	23.9
El Hierro	140.1	105.3	33.9	45.9	89.7	10.0	18.5
Fuerteventura	–	–	–	–	–	–	–
Lanzarote	–	–	–	–	–	–	–
Total	16,181.7	16,484.7	4,706.6	7,502.4	9,879.1	2,625.7	1,715.9

Source: [15].

Table 12
Sum of bananas damaged and bananas withdrawn from the market by islands and year (ton).

Islands	2016	2017	2018	2019	2020	2021	2022
Tenerife	7,032.7	10,313.7	12,601.9	16,891.7	20,920.5	2,290.7	6,351.1
La Palma	7,276.3	12,208.2	7,897.7	10,078.4	12,135.8	24,845.9	2,242.9
Gran Canaria	3,130.9	4,630.7	3,076.1	1,460.1	2,311.1	796.5	658.3
La Gomera	619.8	1,485.5	1,485.9	1,848.3	1,267.0	264.5	1,017.3
El Hierro	178.8	243.3	94.2	251.1	131.0	25.9	86.3
Fuerteventura	–	–	–	–	–	–	–
Lanzarote	–	–	–	–	–	–	–
Total	18,238.5	28,881.4	24,155.9	30,529.6	36,765.3	28,223.5	10,355.8

Source: [15].

Table 13
Percentage of the actual production of damaged bananas and bananas withdrawn from the market per year.

year	2016	2017	2018	2019	2020	2021	2022
%	4.37 %	6.86 %	6.51 %	7.66 %	8.75 %	6.90 %	2.98 %

Source: [15].

combination of first and second generation technologies aimed at converting starch, sugars and lignocellulosic components into bioethanol, the ethanol concentration reaches 46.23 g/l for P (banana pulp only) and 35.90 g/l for PC (banana pulp and peel), which are lower than the concentrations reached by corn (88.2 g/l) and grain sorghum (69.8 g/l).

Table 14
Potential sugars for 30,000.00 tons of bananas/year.

	Banana peel (35 % by weight)		Banana fruit (65 % by weight)		Total, sugars
Total Sugars	%	tone	%	tone	tone
Fructose ($C_6H_{12}O_6$)	6.34 %	665.35	1.98 %	386.10	1,051.45
Glucose ($C_{12}H_{22}O_{11}$)	7.22 %	758.56	2.34 %	456.30	1,214.86
Sucrose ($C_6H_{12}O_6$)	6.44 %	676.09	15.20 %	2,964.00	3,640.09
Total	19.99 %	2,100.00	19.52 %	3,806.40	5,906.40

Source: [15].

Table 15
Productions, production averages, % of productions.

		Total(Tone)	Media Anual (Ton)	% of Total Production (1)	% of Total Production (2)	% of Total Production (3)
Damaged	2017–2021	108,357.26	21,671.45	5.22 %	5.32 %	4.96 %
Recalled	2017–2021	41,198.52	8,239.70	1.98 %	2.02 %	1.89 %
Total	2017–2021	149,555.78	29,911.16	7.20 %	7.35 %	6.84 %
Total Production (1) (including recalls)	2017–2021	2,076,686.61	415,337.32			
Total Production (2) (excluding claims and recalls)	2017–2021	2,035,488.09	407,097.62			
Total Production (3) (including claims and recalls)	2017–2021	2,185,043.87	437,008.37			

Source: [26].

Table 16
Commercialization of bananas from the Canary Islands 2021 (Kg).

Zone	Peninsula	Canary Islands	Other Countries	Total
Kg	368,994,238	37,652,092	2,459,929	409,106,259
%	90.195 %	9.203 %	0.601 %	100.00 %

Source: [26].

Table 17
Field surveys, Canary Islands banana 2021 (Kg).

Tenerife municipalities area	
TF1	Los Silos, Icod de los Vinos, Garachico, El Tanque and Buenavista
TF2	La Matanza, La Orotava, La Victoria, Los Realejos, Santa Úrsula, Puerto de la Cruz, La Guancha, S. Juan de la Rambla Tacoronte, La Laguna and Santa Cruz
TF3	Arafo, Arico, Candelaria, El Rosario, Fasnia, Güímar, Arona, San Miguel de Abona and Granadilla
TF4	Guide to Isora, Adeje and Santiago del Teide
La Palma Municipalities Area	
LP1	El Paso, Tazacorte, Los Llanos, Garafía, Puntagorda and Tijarafe
LP2	Fuencaliente
LP3	Mazo, Santa Cruz, Puntallana, Breña Alta, Breña Baja, Barlovento y S. Andrés y Sauces
Area Municipalities Gran Canaria	
GC1	Arucas, Firgas, Gáldar, Las Palmas, Moya, Santa María de Guía and Teror
GC2	Agüímes, Ingenio, S. Bartolomé Tirajana, S. Lucía, Telde, San Nicolás de Tolentino and Mogán

Source: [26].

Table 18
Carbon Fixation.

	(gCO_2/kg banana produced)
Carbon fixation	**−154.65**

Source: [26].

This is an estimated yield of 0.17821 m^3 of bioethanol per tonne of banana pulp (0.17821 m^3/tonne P) and 0.13839 m^3 of bioethanol per tonne of pulp plus banana peel (0.13839 m^3/tonne PC). This makes a total annual production of banana bioethanol of 4,151.70 m^3 of bioethanol per year from banana pulp and its peel (PC).

The evolution in production compared to fermentation time is shown in the following figure:

3.1.2. Energy and environmental impact of bioethanol produced from bananas in the Canary Islands

The consumption of gasoline in the Canary Islands in 2019 in automotive was 702,834.90 m^3, if the production of banana bioethanol from banana pulp and its peel (PC) of 4,151.70 m^3 per year is used, to produce E-10 Gasoline, 37,365.31 m^3 would be needed to produce the mixture, which would have a volume of 41, 151.70 m^3, reducing consumption to 661,317.89 m^3. would be as shown in the following table.

Se it could market 5.9 % of E-10 gasoline with the bioethanol

Table 19
Carbon footprint of bananas from the Canary Islands. (gCO_2/kg produced) without Valorization.

Field Stage			**78.39**
Manufacturing and transport of inputs			24.01
	In vitro plant production and transport	0.72	
	Manure manufacturing	0.54	
	Manure transport	0.91	
	Fertilizer Manufacturing	18.18	
	Fertilizer Transportation	2.55	
	Manufacture of phytosanitary products	0.14	
	Bag Manufacturing	0.96	
Fertilizer Application			38.60
Power Consumption			11.55
Transport from fruit to packaging			4.24
Packaging Stage			**58.57**
Electricity			7.68
Phytosanitary products			0.03
Manufacturing. Transport. Materials. Packaging			50.86
	Manufacture and end of life of the case	44.61	
	Manufacture and Disposal of Paper Separators	1.20	
	Manufacture and end of life of LDPE bag	2.63	
	Transport of packaging materials	2.41	
Distribution and Maturation Stage			**111.23**
Transport to market			90.92
	Container Trucks	21.72	
	Containers	25.78	
	Ship	42.28	
	Refrigerant gas	1.14	
Maturation			20.31
	Ethylene gas	0.21	
	Power consumption	20.10	
End-of-Life Stage			**27.17**
Transport of waste to landfill			1.91
End of Life			25.26
Fixation (gCO_2/kg banana produced)			**−154.65**
Carbon fixation			−154.65
Total (gCO_2/kg plantain)			**120.71**

Source: [26].

obtained.

There are also environmental repercussions as tCO_{2eq} emissions in automotive petrol in the Canary Islands decrease. These were approximately 1,718,935.91 tCO_{2eq} in 2019 and the impact of bioethanol means that they decreased by 10,153.89 tCO_{2eq}, 0.6 %. The results are shown in the table below.

Table 20
Integration of PC bioethanol into automotive gasoline.

Gasoline type	% mezcla	m^3		%	
Gasoline B10	10.0 %	4,151.70	41,151.70	0.6 %	5.9 %
	90.0 %	37,365.31		5.3 %	
Common Gasoline	–	661,317.89	661,317.89	94.1 %	97.2 %
Total		702,834.90	702,834.90	100.0 %	100.0 %

Table 21
Repercusión del bioetanol de PC en las emisiones de tCO_{2eq} de la gasolina de automoción.

Gasoline type	% mezcla	tCO_{2eq}	%
Gasoline B10	10.0 %	0.0	0.0 %
	90.0 %	91,385.0	5.3 %
Common Gasoline	–	1,617,397.02	94.7 %
Total		1,708,782.02	100.0 %

Table 22
Carbon Footprint of Canary Islands Banana with Valorization. (gCO_2/kg produced).

Field Stage			**78.39**
Manufacturing and transport of inputs			24.01
	In vitro plant production and transport	0.72	
	Manure manufacturing	0.54	
	Manure transport	0.91	
	Fertilizer Manufacturing	18.18	
	Fertilizer Transportation	2.55	
	Manufacture of phytosanitary products	0.14	
	Bag Manufacturing	0.96	
Fertilizer Application			38.60
Power Consumption			11.55
Transport from fruit to packaging			4.24
Packaging stage			**58.57**
Electricity			7.68
Phytosanitary products			0.03
Manufacturing. Transport. Materials. Packaging			50.86
	Manufacture and end of life of the case	44.61	
	Manufacture and Disposal of Paper Separators	1.20	
	Manufacture and end of life of LDPE bag	2.63	
	Transport of packaging materials	2.41	
Distribution and Maturation Stage			**111.23**
Transport to market			90.92
	Container Trucks	21.72	
	Containers	25.78	
	Ship	42.28	
	Refrigerant gas	1.14	
Maturation			20.31
	Ethylene gas	0.21	
	Power consumption	20.10	
End-of-Life Stage			**25.31**
Transport of waste to landfill			1.78
End of Life			23.63
Fixation (gCO_2/kg banana produced)			**−154.65**
Carbon fixation			−154.65
Total (gCO_2/kg plantain)			**118.85**

Table 23
Carbon footprint of bananas from the Canary Islands. (gCO_2/kg produced).

Year	2013	2016	2022	2022 with Valorization
Huella Carbono	249.00	195.16	120.71	118.85

3.2. Carbon footprint

3.2.1. Process map of the life cycle of bananas from the Canary Islands with valorization

It is shown in Fig. 10, Process map of the life cycle of the Canary Islands banana considering the valorization of the banana in the process:

3.2.2. Summary and analysis of the carbon footprint of bananas from the Canary Islands. (gCO_2/kg produced) with valorization

Table 22, Fig. 11 and Fig. 12 show the summary results and analysis of the carbon footprint of bananas from the Canary Islands. (gCO_2/kg produced) with Valorization (see Fig. 13).

The analysis of the inventory of emissions generated in this new situation makes it possible to identify the processes that generate the greatest amount of GHGs. After studying the emissions generated at each stage, the most significant is the distribution and ripening of the total (111.23 gCO_2/kg banana). The field stage is the second most important, it is also conserved with 28.47 % of emissions (78.39 gCO_2/kg banana), as well as the packaging stage with 21.27 % (58.57 gCO_2/kg banana). Finally, end-of-life, which accounted for 9.87 % of GHG emissions (27.17 gCO_2/kg bananas), now accounts for 9.19 % of GHG emissions (25.31 gCO_2/kg bananas).

The processes whose emissions have the greatest weight on the carbon footprint of the Canary Islands Banana are conserved, such as the transport of the fruit to the market (fuel emissions), which account for 33.24 % of them, the manufacture and transport of packaging materials (18.60 %), the application of nitrogen fertilizers (14.11 % of emissions), and the manufacture and end of life of the product decreases to (8.6 %).

3.2.3. Evolution of the carbon footprint

The evolution of the carbon footprint in the production of bananas from the Canary Islands has evolved to date up to 120.71 gCO_2/kg produced, but with recovery it would even reach 118.85 gCO_2/kg.

4. Conclusions

It has been shown that the waste of the Canarian banana can and should be recovered due to its large amount of production, about 30,000.00 tons per year and its easy management.

Such valorization would lead to direct improvements in banana production:

a) Improvement in the carbon footprint of bananas, reducing the footprint by 0.68 % from 120.71 gCO_2/kg produced to 118.85 gCO_2/kg produced.
b) Economic improvement in banana production. This economic improvement is directly in the production of bananas, due to the reduction in landfill costs, since these discharges decrease due to their use in recovery and an improvement due to the transport of landfills, which also decrease due to their reduction in waste in landfills and their use in recovery.
c) Economic improvement due to extraordinary income. This would be possible income from the sale of waste for recovery.

It also leads to improvements in the environment:

– Decrease in emissions to the environment due to the decrease in the carbon footprint.
– Reduction of discharges. About 30,000 tons per year.

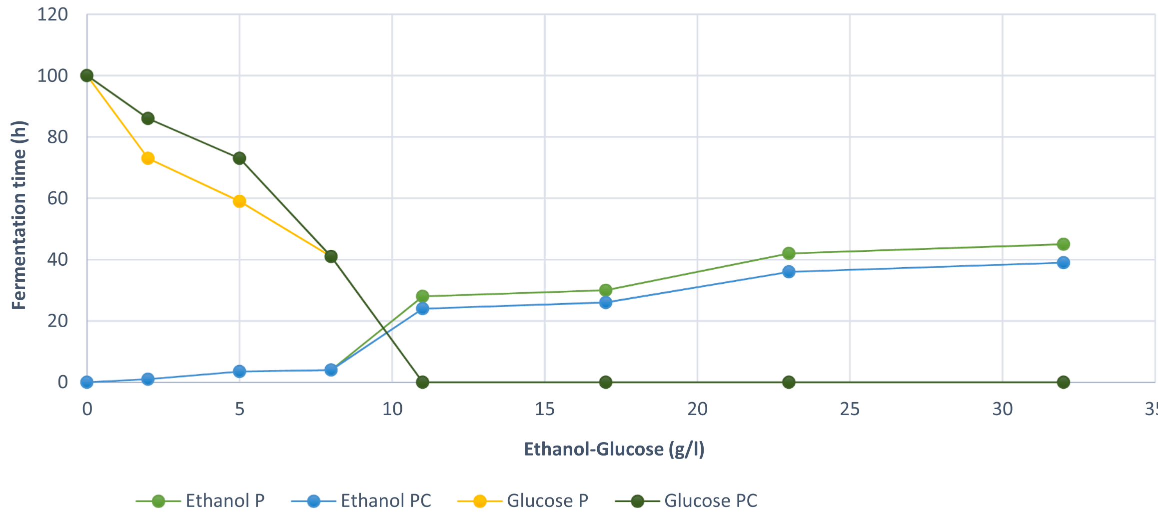

Fig. 10. Evolution of banana bioethanol production. .
Source: [34]

On the other hand, with the valorization of bananas, a path is opened for the projection of this valorization in the obtaining of different products. From the production of sugar in large quantities and/or in the fermentation of waste, which can drive several trades:

- Sugar production and marketing.
- Bioethanol production. It could be used as a fuel that would help decrease the use of fossil fuels, or their commercialization for different uses.
- MEA production. Transformation of ethanol into MEA (mono ethanol amine) for commercialization.
- CO_2 capture. Use of MEA for CO_2 capture.
- Production of synthetic fuels, net zero CO_2 emissions, e-fuels.

Specifically, with the production of bioethanol, the Canary Islands automotive market can be affected by producing 41,1451.70 m^3 of E-10 gasoline, which represents 5.9 % of annual gasoline consumption and reduces polluting emissions by 0.6 %, i.e. 10,153.89 tCO_{2eq}.

Funding

This research was cofunded by the INTERREG V-A Cooperation, Spain–Portugal MAC (Madeira-Azores-Canaries) 2014–2020 program, MITIMAC project (MAC2/1.1a/263).

CRediT authorship contribution statement

Juan Carlos Lozano Medina: Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Resources, Project administration, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Vicente Henríquez Concepción:** Validation, Supervision, Project administration, Methodology. **Carlos A. Mendieta Pino:** . **Federico León Zerpa:** Visualization, Resources, Investigation.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

Appendix

Table 24
Fuel inputs to the Canary Islands for consumption per year (tonne).

Products	2014	2015	2016	2017	2018	2019	2020
Total Raw	**666,360**	**202,495**	**256,210**	**4,5**	**0,2**	**0,002**	**137,983**
Butane	24,264	37,406	35,253	35,085	39,082	33,479	27,366
Propane	40,484	47,665	50,446	51,935	49,348	49,553	24,315
Total GLP	**64,747**	**85,071**	**85,698**	**87,020**	**88,430**	**83,032**	**51,681**
Gasoline 95	248,450	369,808	403,337	371,902	388,943	442,754	218,363
Gasoline 98	69,412	92,105	146,039	145,072	144,347	147,293	93,220
Other Gasolines	50,353	24,195	5,596	105	131	116	66
Aviation gasoline	105	93	91	63	48	83	26
Total Gasoline	**368,320**	**486,201**	**555,064**	**517,142**	**533,469**	**590,245**	**311,675**
Total Diesel	**1,716,616**	**2,061,096**	**2,205,105**	**2,267,166**	**2,155,869**	**2,091,888**	**1,598,410**
Total Fuel Oil	**2,069,468**	**2,647,510**	**2,545,236**	**3,142,145**	**2,870,038**	**2,008,229**	**1,147,135**
Total Kerosene	**826,251**	**940,143**	**1,162,275**	**1,117,845**	**1,259,184**	**1,127,037**	**421,829**
TOTAL TICKETS	**5,711,762**	**6,422,515**	**6,809,588**	**7,131,322**	**6,905,990**	**5,900,431**	**3,668,713**
Total finished products	**5,045,402**	**6,220,020**	**6,553,378**	**7,131,318**	**6,905,990**	**5,900,431**	**3,530,730**

Source: [15].

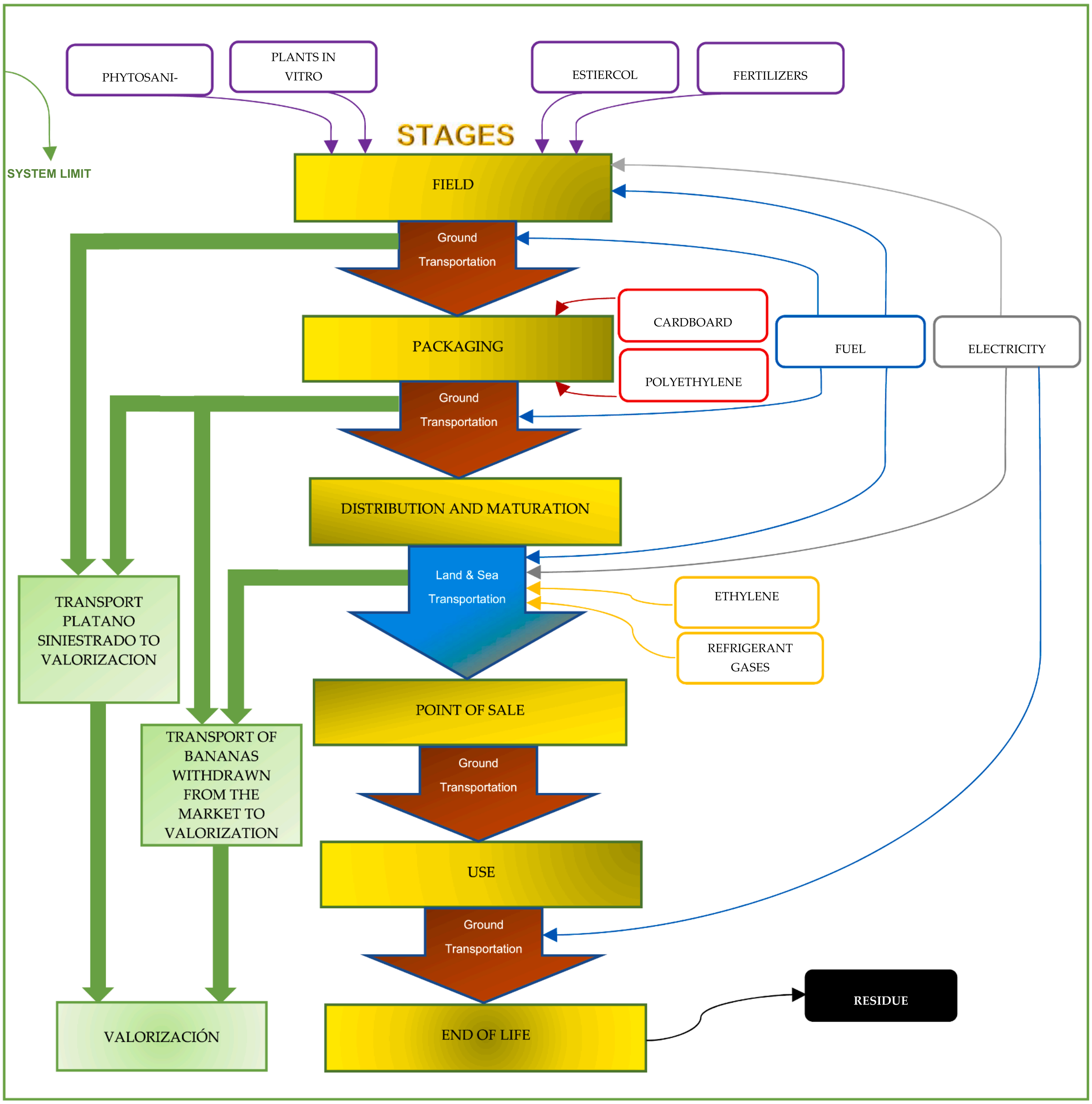

Fig. 11. Process map of the life cycle of Bananas from the Canary Islands with Valorization.

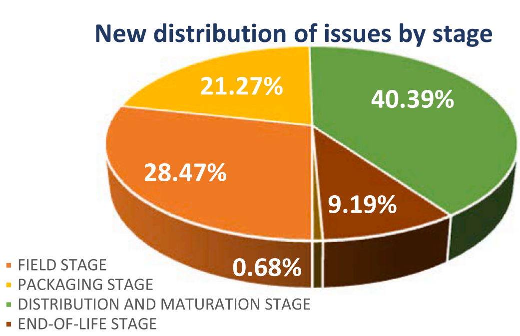

Fig. 12. New distribution of Emissions by stage.

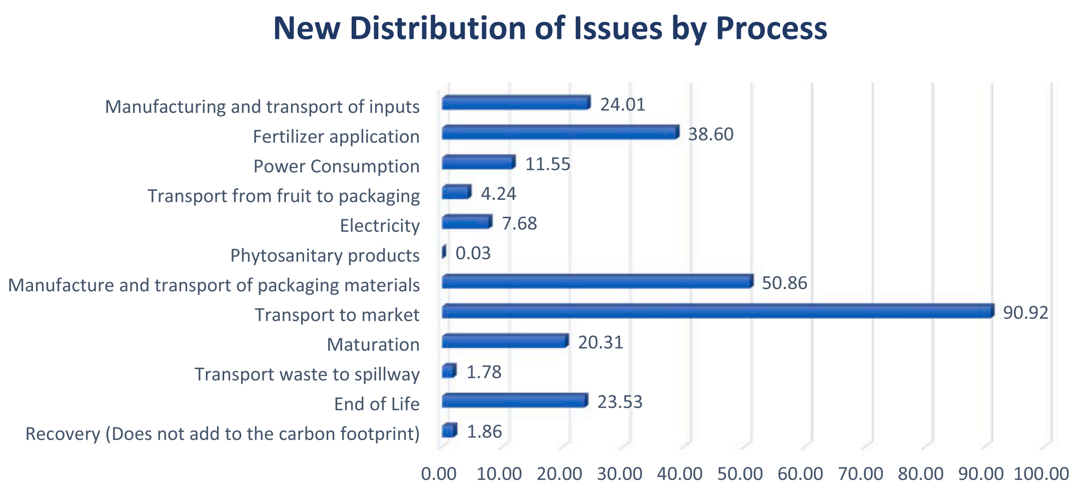

Fig. 13. New distribution of emissions by process.

Table 25
CO_2 emissions (Gg CO_{2eq}) by year and segment. Annual variation.

Year	Energy Processes		Industrial Processes & Product Usage		Agriculture		Waste treatment and disposal		Total	
	Gg CO_{2eq}	Δ	Gg CO_{2eq}	Δ	Gg CO_{2eq}	Δ	Gg CO_{2eq}	Δ	Gg CO_{2eq}	Δ
1990	7.995.02	–	48.13	–	210.20	−14.0 %	483.73	–	8,737.08	–
1991	7.899.73	−0.7 %	49.79	3.4 %	180.85	5.7 %	482.63	−0.2 %	8,613.00	−1.4 %
1992	7.998.37	1.2 %	52.12	4.7 %	191.21	8.6 %	514.82	6.7 %	8,756.52	1.7 %
1993	8.283.71	3.6 %	52.03	−0.2 %	207.61	−2.8 %	542.77	5.4 %	9,086.12	3.8 %
1994	8.959.46	8.2 %	56.59	8.8 %	201.73	−8.8 %	571.93	5.4 %	9,789.71	7.7 %
1995	8.998.99	0.4 %	60.18	6.4 %	184.04	24.3 %	600.93	5.1 %	9,844.14	0.6 %
1996	11,204.44	24.5 %	84.78	40.9 %	228.84	−9.7 %	627.12	4.4 %	12,145.18	23.4 %
1997	10,913.66	−2. 6 %	107.94	27.3 %	206.65	−2.4 %	681.78	8.7 %	11,910.03	−1.9 %
1998	11,425.44	4.7 %	235.17	117.9 %	201.74	−2.9 %	715.93	5.0 %	12,578.28	5.6 %
1999	13,356.34	16.9 %	209.43	−10.9 %	195.95	47.3 %	749.15	4.6 %	14,510.87	15.4 %
2000	13,422.17	0.5 %	262.51	25.3 %	288.60	3.8 %	781.03	4.3 %	14,754.31	1.7 %
2001	13,737.36	2.3 %	316.82	20.7 %	299.52	−7.7 %	824.06	5.5 %	15,177.76	2.9 %
2002	13,623.56	−0.8 %	344.34	8.7 %	276.55	5.4 %	905.95	9.9 %	15,150.40	−0.2 %
2003	14,074.01	3.3 %	397.32	15.4 %	291.54	−3.3 %	970.99	7.2 %	15,733.86	3.9 %
2004	15,473.56	9.9 %	464.59	16.9 %	282.05	2.3 %	1,006.89	3.7 %	17,227.09	9.5 %
2005	15,701.03	1.5 %	542.00	16.7 %	288.45	−5.7 %	1,067.66	6.0 %	17,599.14	2.2 %
2006	14,977.24	−4.6 %	653.03	20.5 %	272.14	1.9 %	1,129.08	5.8 %	17,031.49	−3.2 %
2007	14,658.20	−2.1 %	749.73	14.8 %	277.26	−5.7 %	1,166.68	3.3 %	16,851.87	−1.1 %
2008	15,369.17	4.9 %	799.01	6.6 %	261.45	−8.2 %	1,184.55	1.5 %	17,614.18	4.5 %
2009	13,201.47	−2.1 %	737.28	−7.7 %	239.90	6.5 %	1,173.64	−0.9 %	15,352.29	−12.8 %
2010	13,149.43	4.9 %	741.23	0.6 %	255.45	−3.5 %	1,164.20	−0.8 %	15,310.31	−0.3 %
2011	12,088.56	−14.1 %	746.53	0.6 %	246.59	0.0 %	1,212.13	4.1 %	14,293.81	−6.6 %
2012	11,911.88	−0.4 %	767.11	2.8 %	246.66	−11.7 %	1,210.23	−0.2 %	14,135.88	−1.1 %
2013	10,963.08	−8.0 %	777.81	1.4 %	217.86	11.3 %	1,206.22	−0.3 %	13,164.97	−6.9 %
2014	10,582.40	−3.5 %	776.48	−0.2 %	242.38	−16.0 %	1,179.18	−2.2 %	12,780.44	−2.9 %
2015	10,846.41	2.5 %	469.80	−39.5 %	203.58	7.9 %	1,199.74	1.7 %	12,719.53	−0.5 %
2016	11,302.23	4.2 %	467.81	−0.4 %	219.60	−2.3 %	1,188.25	−1.0 %	13,177.89	3.6 %
2017	11,794.36	4.4 %	397.41	−15.0 %	214.48	−10.4 %	1,128.83	−5.0 %	13,535.08	2.7 %
2018	11,754.98	−0.3 %	354.15	−10.9 %	192.20	−2.5 %	1,064.56	−5.7 %	13,365.89	−1.3 %
2019	11,455.83	−2.5 %	346.77	−2.1 %	187.40	−14.0 %	1,047.85	−1.6 %	13,037.85	−2.5 %

Source: [35].

Table 26
Supply to the Automotive market of gasoline (tonnes).

Products	Gran Canaria	Tenerife	Lanzarote	Fuerteventura	La Palma	La Gomera	El Hierro	Canarias
Gasoline 95	144,491	167,347	39,879	27,933	12,334	2,204	1,438	395,626
Gasoline 98	42,016	70,633	3,521	4,646	5,350	1,003	817	127,987
Suma	**186,507**	**237,980**	**43,400**	**32,579**	**17,684**	**3,206**	**2,255**	**523,612**

Source: [15].

Table 27
Agricultural production in the Canary Islands. Year 2020, (tonne).

Crops	Tons/year	%
Cereals	1,992.0	0.22 %
Legumes Grain	298.7	0.03 %
Potato	78,150.7	8.51 %
Other tubers	4,582.0	0.50 %
Industrial Crops	8,795.4	0.96 %
Cut Flower	3,608.0	0.39 %
Ornamentals & Cuttings	8,497.2	0.93 %
Forage Crops and P.	19,881.6	2.17 %
Tomato Export	35,981.1	3.92 %
Local Tomato	29,408.8	3.20 %
Cucumber	35,252.4	3.84 %
Pepper	18,449.5	2.01 %
Green bean	4,760.7	0.52 %
Onion	8,080.2	0.88 %
Strawberry & Strawberry	2,318.4	0.25 %
Watercress	858.5	0.09 %
With the	11,266.2	1.23 %
Lettuce	32,657.6	3.56 %
Melon	6,127.0	0.67 %
Courgette	23,043.5	2.51 %
Carrot	7,855.3	0.86 %
Other vegetables	70,418.9	7.67 %
Orange tree	12,413.8	1.35 %
Other citrus fruits	5,342.7	0.58 %
Banana	420,144.1	45.77 %
Avocado	13,293.4	1.45 %
Papaya	18,318.1	2.00 %
Mango	8,745.7	0.95 %
Tropical Pineapple	2.327.5	0.25 %
Other Fruit Trees	12,425.4	1.35 %
Vineyard	11,961.0	1.30 %
Olive grove	735.9	0.08 %
Other	46.3	0.01 %
TOTAL	918,037.6	100.00 %

Source: [15].

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