Original Article

WM&R

Waste Management & Research
1–11

DOI: 10.1177/0734242X221123493
journals.sagepub.com/home/wmr
SAGE

Environmental implications of reprocessing agricultural waste into animal food: An experience with rice straw and citrus pruning waste

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Abstract
The aim of this study is to conduct an environmental comparison, by applying the life cycle assessment (LCA) methodology, of two different compositions for animal foods each with two different nutritional contents ('high' for the lactation period, and 'low' for the rest of the year). Thus, for each nutritional content, the environmental performance of producing animal feed with a traditional composition mainly based on cereals is compared with a composition based on a mixture of biomass obtained from rice straw and citrus pruning waste. It was observed that the reprocessing of rice straw and citrus pruning waste into animal feed offered environmental potential compared to the current alternative of being burned in the fields. The environmental impact category *global warming* is especially improved, with impact reductions of up to 50% and 95%, respectively, for high and low nutritional content compositions. In addition, the alternatives proposed herein make it possible to avoid all the inconvenience and impacts on the health of the population living near the fields.

Keywords
Biowaste, LCA, life cycle assessment, environmental performance

Received 13th October 2021, accepted 9th August 2022 by Associate Editor Nemanja Stanisavljevic.

Introduction

In the framework of the circular economy (European Commission, 2020), identifying options for the recovery of waste from agricultural production is a priority both for generators and for the research community. Agricultural production waste is easily available in large quantities, especially in Mediterranean countries (Vamvuka et al., 2014) such as Spain, where 47.6% and 57% of the European rice and citrus fruits, respectively, were produced in 2019 (MAPA, 2020).

The increase in rice cultivation over the last decade is associated with a rise in the amount of biomass waste generated (Satlewal et al., 2018). The current practices implemented to manage the straw remaining in the fields after the rice harvest entails associated economic costs and damage to the environment (Sharma et al., 2020). The widespread production of citrus such as oranges and mandarins in Mediterranean areas (Velázquez-Martí et al., 2013) requires annual pruning to optimise the health of the trees and guarantee the quality of the fruits, which also has to be managed.

Up to 20% and 47% of the Spanish rice and orange cultivation is concentrated on the east coast of Spain, specifically in the Valencian region (MAPA, 2020). The method most commonly used to manage the rice straw and citrus pruning waste in this region is to burn it, since it is an effective and cheap traditional biomass waste management technique (Allam and Garas, 2010). However, the burning of biomass in fields causes negative effects on the environment and the health of people living in the surrounding areas (Usmani et al., 2021); at the same time it also prevents it from being reprocessed into secondary material, which is what is promoted by the principles of the circular economy (European Commission, 2020; MacArthur, 2012). Thus, finding alternative ways to process biomass waste, mainly based on its recovery, is becoming one of the main objectives both for government officials and for researchers (Vadrevu et al., 2019).

Different alternatives can be found in the literature for reprocessing rice straw and citrus pruning waste. Their application as building material was analysed by Dede et al. (2021) as a growing media in green wall, Ricciardi et al. (2020) as

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additives to produce thermal and acoustic insulation panels, Usubharatana and Phungrassami (2019) as thermal insulation material or Garas et al. (2015) as sustainable light weight cementitious-straw bricks. Their application for energy purposes was analysed by Magnago et al. (2020) for producing briquettes as source of heat, Migo-Sumagang et al. (2020) for their harnessing for drying applications, Singh and Basak (2019) for comparing advanced techniques such as incineration, gasification or anaerobic digestion for electricity and ethanol production energy or Sagani et al. (2019) for electricity generation from direct combustion of pruning residues. Their application for fuel for bio-refineries was analysed by Demichelis et al. (2020) and Sreekumar et al. (2020) for bioethanol production, Im-orb and Arpornwichanop (2020) for methanol and bio-oil production or González et al. (2011) for pulping and combustion processes. Their application as industrial agent was analysed by Espinach et al. (2020) as reinforcement of bio-polyethylene matrixes, Reixach et al. (2015) as improvement of the acoustic properties of natural fibre for reinforced composites or Espinosa et al. (2020) for obtaining lignocellulose nanofibers for paperboard recycling processes. And finally, their application as animal feed was analysed by Wang et al. (2019) in China, Bisaria et al. (1997) and Bakshi et al. (2016) in India, Falls et al. (2017) in United States or (Pérez-Neira et al., 2020) or Fernández et al. (2019) and Huanca et al. (2021) in Spain.

According to Usmani et al. (2021), the life cycle assessment (LCA) methodology (ISO 14040, 2006; ISO 14044, 2006) is a very useful tool for assessing the environmental implications of alternatives for the management of biomass waste. The reprocessing of rice straw and citrus pruning waste into animal feed is a management technique with the double capability of avoiding the environmental impact resulting from burning it and also enriching the animal feed from the protein point of view (Bakshi et al., 2016; Ugwuanyi, 2008). Despite this, few publications assessed the environmental advantage that this reprocessing alternative provides, most of the ones being LCA studies applied to assess the environmental performance of biomass waste recovery. For example, Alhazmi and Loy (2021) compared the environmental impacts of different biomass valorisation-based thermochemical conversion technologies, Demichelis et al. (2020) assess the environmental performance of bioethanol production from waste biomass, Migo-Sumagang et al. (2020) of a small-scale rice-straw-based heat generation system using a downdraft furnace and a dryer simulator setup, Quispe et al. (2019) of producing energy from rice husk as an alternative energy source to coal, Shafie et al. (2014) of rice straw-based power generation, etc. Other studies compared the environmental performance of the rice straw open burning or/and soil incorporation practices with other valorisation alternatives: Shang et al. (2020) with particleboards, cement bonded and electricity generation; Soam et al. (2017) with fodder, biogas and electricity generation; Yodkhum et al. (2018) with electricity generation; Amarante et al. (2018) with electricity generation from biogas, among others.

The present research aims to analyse the environmental performance of the reprocessing of rice straw and citrus pruning waste into animal food, and to compare it against the environmental performance of other traditional formulas. To this end, the LCA methodology will be applied to biomass waste recovery produced in the Spanish Mediterranean area. Specifically, this research studies the case of the Valencian region, which has a cultivated area of 23,000 km^2 specialised in growing rice and citrus fruits.

Definition of scenarios

Four different scenarios for the reprocessing of rice and citrus harvest waste into animal feed are proposed by combining two parameters at two different levels (Table 1):

- nutritional content of the animal food: (1) high nutritional content (for the lactation period), and (2) low nutritional content (for the rest of the year).

Table 1. Scenarios for animal feed under study.

		Biomass waste	
		Yes (a)	No (b)
Nutritional content	High (1)	Sc1a 30% Pretreated citrus pruning waste 19% Pretreated rice straw waste $51\%\ \text{High protein mix}\ (a)\left\{\begin{array}{l}4.92\%\ \text{Cereals}\\ 20\%\ \text{Spring peas}\\ 19\%\ \text{Broad beans}\\ 2\%\ \text{Cane molasses}\\ 3\%\ \text{Vegetable oil fat}\\ <1\%\ \text{Other components}\end{array}\right.$	Sc1b $100\%\ \text{High protein mix}\ (b)\left\{\begin{array}{l}40.6\%\ \text{Cereals}\\ 35\%\ \text{Soy husk}\\ 10\%\ \text{Spring peas}\\ 10\%\ \text{Broad beans}\\ 2\%\ \text{Cane molasses}\\ 1.26\%\ \text{Calcium carbonate}\\ \text{Others}\\ <1.5\%\ \text{Otros componentes}\end{array}\right.$
	Low (2)	Sc2a 100% Pretreated citrus pruning waste	Sc2b 100% Alfalfa

- biomass waste: (a) total or partial incorporation of reprocessed rice/citrus harvest waste, and (b) no incorporation of biomass waste.

A traditional composition based on a mixture of different cereals (high protein mix or alfalfa) is used exclusively in scenarios Sc1b and Sc2b, respectively, and combined with the biomass waste in scenario Sc1a. Scenario Sc2a is based entirely on biomass waste.

Regarding scenarios comparing animal feed with low nutritional content, the effect of substituting alfalfa (Sc2b) with citrus leaves (Sc2a) as forage in diets with low nutritional content has been demonstrated a feasible practice by Fernández et al. (2019) since there is no detrimental effect on nutrients balance and milk yield of goats. In addition, this practice has demonstrated a reduction of the methane emissions. And regarding scenarios comparing animal feed with high nutritional content, Huanca et al. (2021) demonstrated that the inclusion of citrus leaves and rice straw by-products in combination with a mix of soy/cereals for dairy goats increases the fat content in milk without negative effects on cheese yields. In addition, Huanca et al. (2021) concluded that the use of crop residues could be an interesting strategy to reduce feeding costs in producing areas, contributing to the sustainable management of agricultural waste.

The process of preparing the animal feed for each scenario (Table 1) is described in detail below, but basically consists in pretreating rice straw, citrus pruning waste and alfalfa, and then pelletising it. Note that the high protein mixes do not require pretreatment processes since their ingredients are incorporated directly during the pelletising process.

- **Pretreatment of Rice straw (used in Sc1a)**. Based on primary data related to the current rice straw waste management practices carried out by local companies in Valencia/Spain (LIFE16/CCM/ES/000088, 2017), the following unit processes were identified:
    - Rice straw baling. The rice straw waste collection and baling processes are carried out by means of a tractor that pulls a ‘baler’ (see Figure 1(1a)). The baler is powered by the tractor itself, so the total diesel consumption is that of the tractor. The straw baling process usually begins at 11 a.m., when the straw is driest. After gathering the straw in bales, they are deposited in the field separately. Two types of bales were identified depending on the baling process:
        - Big bales: cylindrical bales each weighing 225 kg (see Figure 1(1b)). These are baled using plastic strips.
        - Small bales: cubic bales each weighing 17.5 kg. These are pressure baled and do not require additional fasteners.
    - Collection of bales. The rice straw bales, which are scattered around the field, are collected by an adapted tractor that incorporates a double ‘spike’ to hook, move and load the bales onto the trailer (see Figure 1(1c)).
    - Intermediate transport. The bales are transported by a tractor with a trailer to a nearby place, where they are stored. Generally, they are stored outdoors, so the intermediate storage time is usually short in order to minimise the deterioration of the bales due to meteorological phenomena.
    - Punching and loading bales. The bales are punched and loaded onto a transport truck (truck with a platform) with the help of the same tractor that collects them from the field (see Figure 1(1c)).
    - Final transport and unloading. Final transport depends exclusively on the bale consumer, who usually provides the transport truck. Two types of transport trucks are often used:
        - Small transport truck: with a capacity to transport 80 small bales or 10 big bales (see Figure 1(1d)).
        - Large transport truck: with a capacity to transport 150 small bales or 16 big bales.
- **Pretreatment processes for citrus pruning waste (used in Sc1a and Sc2a)**. Analogously, based on primary data related to the current citrus pruning waste management practices carried out by local companies in Valencia (LIFE16/CCM/ES/000088, 2017), the following processes were identified:
    - Collection and crushing (in the field). At the same time the citrus pruning waste is being collected, it is initially crushed to facilitate its transport and storage (see Figure 1(2a)). The primary crusher used (which incorporates different dump trucks with different capacities to store the pre-crushed waste) is pulled by a tractor (see Figure 1(2b)).
    - Intermediate transport. The crushed citrus pruning waste must be transported to the plant, where it will be treated. This requires an additional tractor with a loading capacity that admits up to three dump trucks.
    - Unloading and intermediate storage. When the citrus pruning waste arrives at the plant, it is unloaded and spread manually on the ground to facilitate its natural drying during the storage time.
    - Leaf-chip separation. Once in the plant, the first treatment consists in separating the leaf from the chips by gravity. To do so, the citrus pruning waste is raised up to an elevated blower (see Figure 1(2c)), which moves the leaves on to the next stage, while the chips fall due to gravity and are accumulated.
    - Internal transport by conveyor belts. Both the chips and the separated leaves are moved by a conveyor belt through the next stages of the pretreatment process.
    - Drying (trommel) (see Figure 1(2d)). The leaves are introduced into a trommel, where they are dried at a low temperature to attain a 37.5% reduction in weight. The hot air injected into the trommel comes from the burning of both the chips that have previously been separated and commercial pellets.

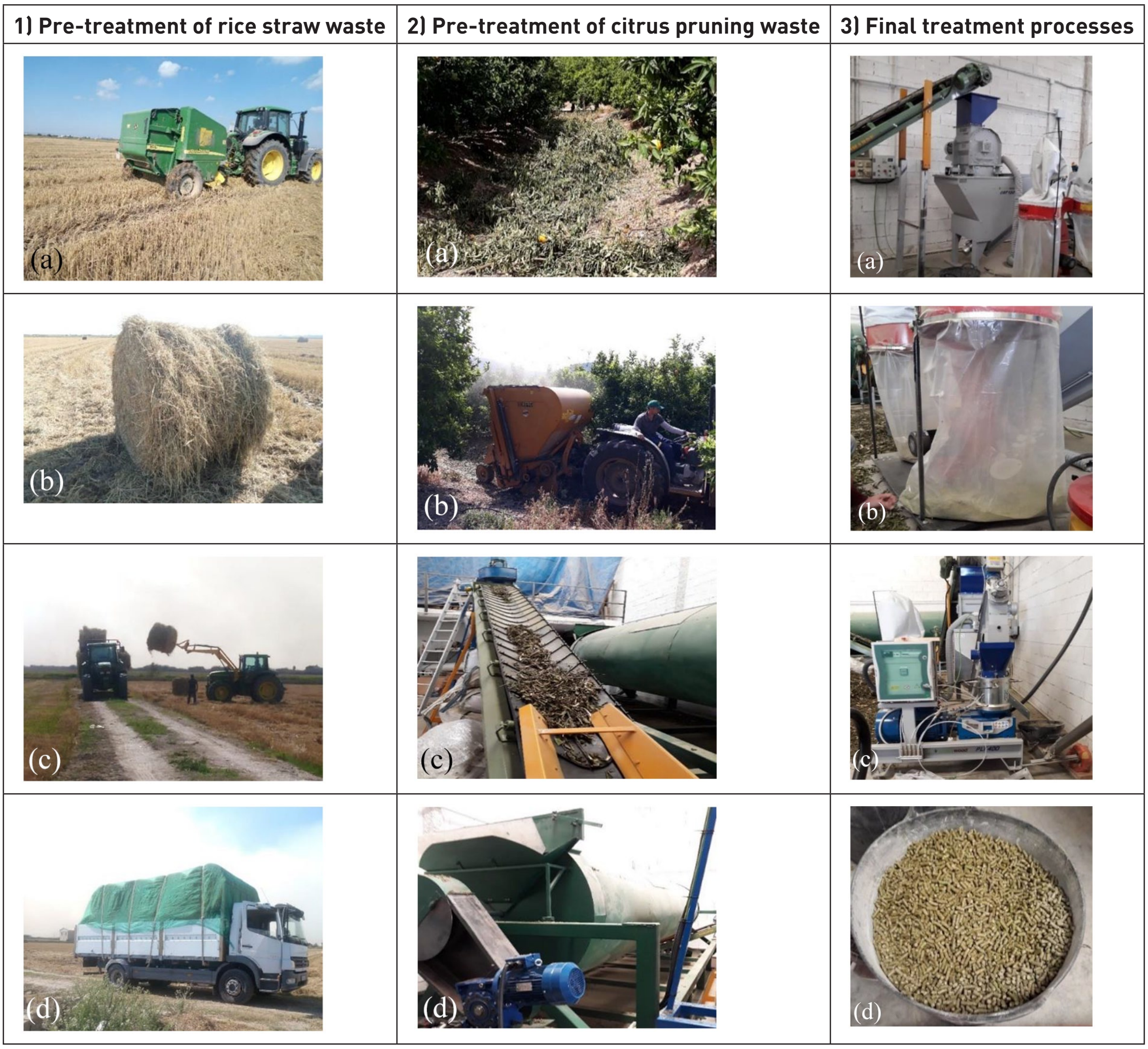

Figure 1. Pretreatment of rice straw (1), pre-treatment of citrus pruning waste (2) and final pelletised product (3).

- **Pretreatment processes of the alfalfa (used in Sc2b)**. Based on AlfalfaSpain (2020), the following practices carried out for the cultivation of alfalfa in Spain were identified:
  - Baling, collection and transport. These stages are the same as those detailed above for rice straw, considering the use of both big bales and large trucks.
  - Drying (trommel). The drying stage is the same as that detailed above for citrus pruning waste, but adapting the humidity data to those detailed by AlfalfaSpain (2020). Specifically, the alfalfa should be dried until it reaches a humidity of 12%.
- **Pelletising process.** Once the ingredients needed for each scenario (Table 1) have been prepared (pretreated ingredients and/or high protein mixes), they are mixed, crushed and pelletised so as to transform them into animal food, following the processes described below:
  - Loading and internal transport. All the ingredients needed for each alternative scenario (see Table 1), respectively, are loaded onto the conveyor belt used to transport them to the mill (see Figure 1(3a)).
  - Final milling. The ingredients needed for each scenario are mixed and ground in a mill to obtain a homogeneous flour. The mill has a dust aspiration system, which reintroduces the aspired flour dust into the process (see Figure 1(3b)).
  - Pelletising. The flour is subjected to a pressure process in a pelletiser, which results in the finished animal feed pellets (see Figure 1(3c, d)).

Environmental assessment of alternative scenarios

The LCA methodology (ISO 14040, 2006; ISO 14044, 2006) allows the environmental performance of systems to be assessed, throughout their entire life cycle. This methodology is especially accepted as a decision-support tool to identify appropriate environmental solutions for waste management (Laurent et al., 2014a, 2014b). According to the ISO 14040 (2006) guidelines, the following stages need to be considered when applying LCA: goal and scope definition, life cycle inventory (LCI), life cycle impact assessment (LCIA) and interpretation of the results.

Goal and scope definition

The main aim of this study is to conduct an environmental analysis of the four alternative scenarios described in Table 1, using mainly primary data collected directly from Spanish companies involved in the production of waste biomass and its management. In addition, it also aims to compare the environmental performance of two different compositions (traditional vs reprocessed) for two different nutritional contents (high and low). Hence, the environmental impact of scenarios with high nutritional content will be compared (Sc1a (traditional composition) vs Sc1b (composition with reprocessed waste biomass)). Analogously, the environmental impact of scenarios with low nutritional content will be compared (Sc2a (traditional composition) vs Sc2b (composition with reprocessed biomass)).

For each alternative scenario under study, the scope considers the life cycle stages shown in Figure 2 and described in Definition of scenarios. Figure 2 also shows the mass balance for each scenario, including the detail of the unitary processes involved in the pretreatment of those ingredients coming from the reprocessing of rice straw, citrus pruning waste and alfalfa. The system boundary for each alternative scenario includes all the inputs (raw materials, energy and water) and outputs (airborne, soil and waterborne emissions and solid waste) in each corresponding stage. The environmental burdens due to the machinery and infrastructures required at each of the stages lies beyond the scope of this study. The functional unit (FU) selected for the LCA case study is the preparation of 1 kg of animal feed pellets with the compositions reported in Table 1 for each scenario.

Life cycle inventory

The LCI model of each scenario described in Table 1 was carried out according to ISO/TR 14048 (2002) guidelines.

Tables 2 and 3 show the inventory data for the pretreatment processes applied to citrus pruning and rice straw waste described above. The LCI model was drawn up from field-primary data gathered directly from the local companies in charge of the collection and management of each biomass waste stream.

Citrus pruning waste is currently disposed in the geographical area under study by using two different techniques: burning (32%) and shredding and subsequent spreading in the soil (68%). Table 4 reports the emission rates due to the burning and shredding and spreading the citrus pruning waste, according to Junta de Andalucía (2009) and Brady and Weil (2004), respectively. Rice straw waste is currently disposed by using two different techniques: burning (75%) and spreading in the soil (25%). Table 4 reports the emission rates for both practices with the rice straw waste, according to Sanchis (2014). According to Junpen et al. (2018) and Sharma et al. (2020), among others, the practice of

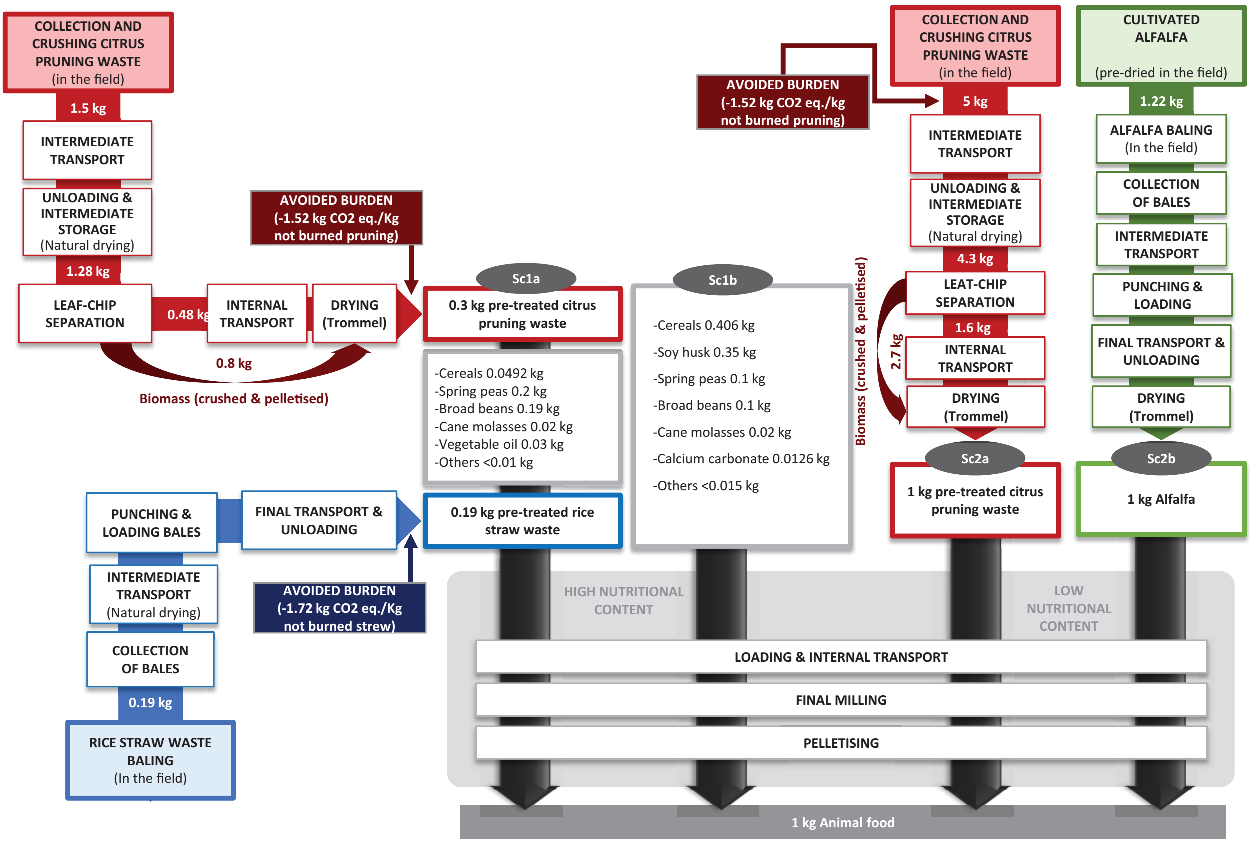

Figure 2. System boundaries: mass balance for the four alternative scenarios under study (Sc1a, Sc1b, Sc2a and Sc2b).

Table 2. Inventory data: pretreatment for citrus pruning waste used in Sc1a and Sc2a (FU: 1 kg of citrus pruning ready to be used as animal food).

	Unit	No. dump trucks		
		1	2	3
Collection and crushing (in the field)				
Diesel	l	5.98E-03		
Intermediate transport				
Diesel	l	1.14E-02	5.70E-03	3.80E-03
Unloading and intermediate storage				
Diesel	l	1.53E-02	1.76E-02	1.72E-02
Leaf-chip separation				
Electricity	kWh	3.20E-01		
Internal transports by conveyor belts				
Electricity	kWh	6.40E-02		
Drying (trommel)				
Electricity	kWh	2.28E-01		
Pellet	kg	4.30E-01		

Table 3. Inventory data: pretreatment of rice straw waste (FU: 1 kg of rice straw ready to be used as animal food).

	Unit	Small bales	Big bales
Rice straw baling (in the field)			
Diesel	l	5.03E-03	1.10E-02
Lubricant	kg		2.90E-06
PP Strip	kg		7.99E-04
Collection of bales			
Diesel	l	1.51E-02	1.76E-03
Intermediate transports			
Diesel	l	1.13E-02	7.04E-03
Punching and loading bales			
Diesel	l	1.51E-02	1.76E-03
Final transports			
Diesel (*small truck*)	l	1.70E-02	1.06E-02
Diesel (*large truck*)	l	1.36E-02	9.90E-03

Table 4. Burden avoided due to obtain animal feed from citrus pruning waste and rice straw waste.

	Emission rate (kg/kg of waste)						
	CO_2	CH_4	N_2O	CO	NO_x	CO_2 eq	CO_2 eq
Citrus waste							
Burning (32%)	1.70	0.003	0.0002	0.069	0.01	1.83	1.52
Shredding and spreading (68%)	1.32	0.003				1.37	
Rice straw waste							
Burning (75%)	1.08	0.023				1.57	1.72
Spreading (25%)	2.15	0.102				2.15	

burning in an open field and the incorporation of waste in soil has a notable negative impact on the environment mainly due to the greenhouse emissions, CO_2 from the combustion during the burning practice and CH_4 from the decomposition of the waste in the spreading practice. Taking into account these data, the avoided burdens due to obtain animal feed from citrus pruning waste and rice straw waste are 1.52 kg CO_2 eq. and 1.72 kg CO_2 eq. per kg for citrus pruning and rice straw waste, respectively (LIFE16/CCM/ES/000088, 2017). These values are in line with the emissions reported by Ortiz De Zárate et al. (2000) (1.4 kg CO_2 eq./kg dry straw), Zhang et al. (2000) (1.13 kg CO_2 eq./kg dry straw) and Andreae and Merlet (2001) (1.515 kg CO_2 eq./kg dry straw) from diverse agricultural residues, and Sahai et al. (2007) (1.787 kg CO_2 eq./kg dry straw) for wheat straw.

Table 5 shows the inventory data for the alfalfa pretreatment processes described in Definition of scenarios. The LCI model was drawn up from secondary data gathered from AlfalfaSpain (2020) and the LCI data was modelled using the Agri-Footprint v4.0 (2017) database for the cultivation of alfalfa, and Ecoinvent 3.5 (2018) database for the preparation of the pellets (electricity, diesel, etc.).

Table 5. Inventory data: pretreatment for alfalfa used in Sc2b (FU: 1 kg of alfalfa ready to be used as animal food).

	Unit	Quantity
Alfalfa baling (in the field)		
Diesel	l	1.35E-02
Lubricant	kg	3.54E-06
PP Strip	kg	9.74E-04
Collection of bales		
Diesel	l	2.15E-03
Intermediate transport (short distance)		
Diesel	l	8.59E-03
Punching and loading bales		
Diesel	l	2.15E-03
Final transport		
Distance	tkm	1.22E-01
Internal transports by conveyor belts		
Electricity	kWh	7.80E-02
Dryer (trommel)		
Electricity	kWh	1.73E-01
Pellet	kg	3.28E-01

Table 6 details the inventory data for the high protein mixes (a & b) to be used in scenarios Sc1a and Sc1b. These secondary data came from Ecoinvent 3.5 (2018) and Agri-Footprint v4.0 (2017) databases.

Finally, the LCI model for the pelletising process was based on electricity consumption, modelled using the Ecoinvent 3.5 database (Ecoinvent 3.5, 2018). The consumptions involved in this process for loading and internal transports, milling and pelletising, referenced to the FU (1 kg of animal food), were 0.040, 0.114 and 0.045 kWh, respectively.

Note that the Spanish electricity mix was considered when modelling data for all the processes under study.

Life cycle impact assessment

An attributional LCA modelled with a 'cradle-to-grave' approach was conducted in accordance with the ISO 14040 (2006) and ISO 14044 (2006) guidelines and by applying SimaPro v8.3 (2018). The following seven impact categories were considered by using the CML mid-point LCIA method (Guineé, 2002): acidification (kg SO_2 eq.) (AC), eutrophication (kg PO_4^3 eq.) (EP), global warming (kg CO_2 eq.) (GWP), ozone layer depletion (kg CFC^{-11} eq.) (ODP), photochemical oxidation (kg C_2H_4 eq.) (POP), human toxicity (kg 1,4-DCB eq.) (HT) and abiotic depletion (kg Sb eq.) (ADP).

A preliminary LCA study was conducted to select the best environmental combination for the biomass waste pretreatment

Table 6. Inventory data: high protein mixes a and b used in Sc1a and Sc1b (FU: 1 kg of animal food).

High protein MIX a (Sc1a)			Origin
Name	Proportion (%)	Element from *Ecoinvent 3.5 database*	
Vegetable oil fat	3	Fatty acid {RER}| fatty acid production, from palm oil	International
		Element from *Agri-footprint v.4 database*	
Cereals	4.92	Barley grain, at farm	National
Broad beans	19	Beans, dry, at farm	National
Spring peas	20	Pea, at farm	National
Cane molasses	2	Sugar cane molasses, consumption mix, at feed compound plant	International
Others	<1	–	–
High protein MIX b (Sc1b)			**Origin**
Name	Proportion (%)	Element from *Ecoinvent 3.5 database*	
Calcium carbonate	1.26	Calcium carbonate {RER}| Calcium carbonate production	International
		Element from *Agri-footprint v.4 database*	
Cereals	40.6	Barley grain, at farm	National
Soy husk	35	Soybean hulls, from crushing, at plant	National
Broad beans	10	Beans, dry, at farm	National
Spring peas	10	Pea, at farm	National
Cane molasses	2	Sugar cane molasses, consumption mix, at feed compound plant	International
Others	<1	–	

processes, in order to identify the best environmental combination of the number of dump trucks (Table 2) for citrus pruning waste and the type of rice straw bale, the transport truck size and the level of consumption (Table 3) for the rice straw. The results are reported in the Supplemental Figures A and B and support the selection of the following combination for:

- Pretreatment processes for rice straw: big cylindrical bale and large transport truck, with a capacity to transport 16 big bales.
- Pretreatment processes for citrus pruning waste: a truck with a capacity for storing three dump trucks of the pre-crushed waste.

Figure 3 shows the LCIA results by impact category and by unit process (pretreatment/pelletising). The left column compares the results for scenarios of animal feed with high nutritional content (Sc1a vs Sc1b), while the column on the right compares scenarios with low nutritional content (Sc2a vs Sc2b).

Interpretation of the results

For scenarios with high nutritional content (Sc1a vs Sc1b, left column in Figure 3), it is observed that the proposed formulated feed (Sc1a), which includes partially reprocessed rice straw/citrus pruning waste, improves the environmental impact compared with that of the feed with a traditional composition (Sc1b) in all the impact categories except for AC, where the impact can be considered equal.

For scenarios with low nutritional content (Sc2a vs Sc2b, right column in Figure 3), it is observed that the proposed formulated feed (Sc2a), which includes partially reprocessed citrus pruning waste, presents a lower environmental impact for almost all the impact categories, except for ODP andPOP, than the feed with a traditional composition (Sc2b).

The most significant reduction in environmental impact in both comparisons (high and low nutritional content, right and left column in Figure 3, respectively) is observed for global warming, followed by HT and ADP. This is due to the fact that, when producing the proposed formulated animal food, besides the environmental avoided burdens derived from not having to produce alternative feed components (such as cereals or soy husk), the emission of 1.5 kg of CO_2 eq. for each kg of animal feed produced by burning the citrus pruning and rice straw waste is also avoided.

On analysing the stages of the animal feed production, it is observed that the raw material pretreatment processes are those with a higher contribution for all impact categories. Conversely, final treatment processes (loading and internal transports, milling and pelletising) make a low contribution. The high environmental impact of citrus pruning waste pretreatment is mainly caused by the drying stage, where the citrus leaves are introduced into a trommel to be dried at a low temperature. Note that, even though the rice straw and citrus pruning waste pretreatments present a high environmental impact, that resulting from the preparation of the high protein mixes is even higher.

The significant environmental impact associated with the cultivation of the alfalfa should also be highlighted, since it accounts for up to half the contribution to the impact in categories such as AC, POP or ODP. The substitution of alfalfa by reprocessed citrus pruning waste avoids the cultivation stages of the original ingredient and requires biomass waste pretreatment processes with a lower impact, for all categories except POP or ozone layer depletion, than the preparation of alfalfa as a whole. Consequently, the incorporation of reprocessed citrus pruning waste in animal feed offers a significant environmental advantage.

Conclusions

This paper presents a comparative LCA of different formulations of animal feed (for high and low nutritional content), including traditional compositions and proposed compositions including reprocessed rice straw and citrus pruning waste coming from the Valencian region, in Spain.

The results show that the incorporation of biomass waste in animal feed offers an important environmental advantage, derived from the improvement that the raw material pre-treatment processes entails. Specifically, the proposed formulated feed alternatives (Sc1a and Sc2a) present significant reductions in impact contributions, mainly for the global warming potential, with reductions of up to 50% and 95%, respectively, for the two types of scenarios (high and low nutritional content). These environmental advantages are due, on the one hand, to avoiding the need to cultivate cereals, soy and alfalfa, which are basic components in the traditional animal feed alternatives and make high contributions to the impacts. Avoiding these crops or making them more sustainable would reduce the contribution to all impact categories, in general, and more especially to POP, HT and ADP. On the other hand, the avoided burden derived from eliminating the processes of burning biomass waste in the fields has a very significant effect on the impact category global warming.

When comparing the animal feed alternatives with low nutritional content (Sc2a vs Sc2b), the formulated feed proposed here (Sc2a) presents worse environmental behaviour for the ozone layer depletion category than Sc2b. This is due to the citrus pruning waste pretreatment process, which needs far more energy due to it being dried with a trommel than the energy needed for the air-dried alfalfa. This highlights the importance of air pre-drying for reprocessing biowaste as animal feed in order to minimise the energy demand of the pretreatment processes, for example, by means of laying out and storing the citrus pruning waste in fields where it can be dried in the sun.

Hence, it can be concluded that rice straw and citrus pruning waste offer a big potential for being reprocessed into animal feed as an alternative to being burned. The main advantage of this process is that in addition to improving the environmental impact of animal feed production, especially the contribution to the impact category global warming, it also makes it possible to avoid all the inconvenience and impacts on the health of the population living near the fields.

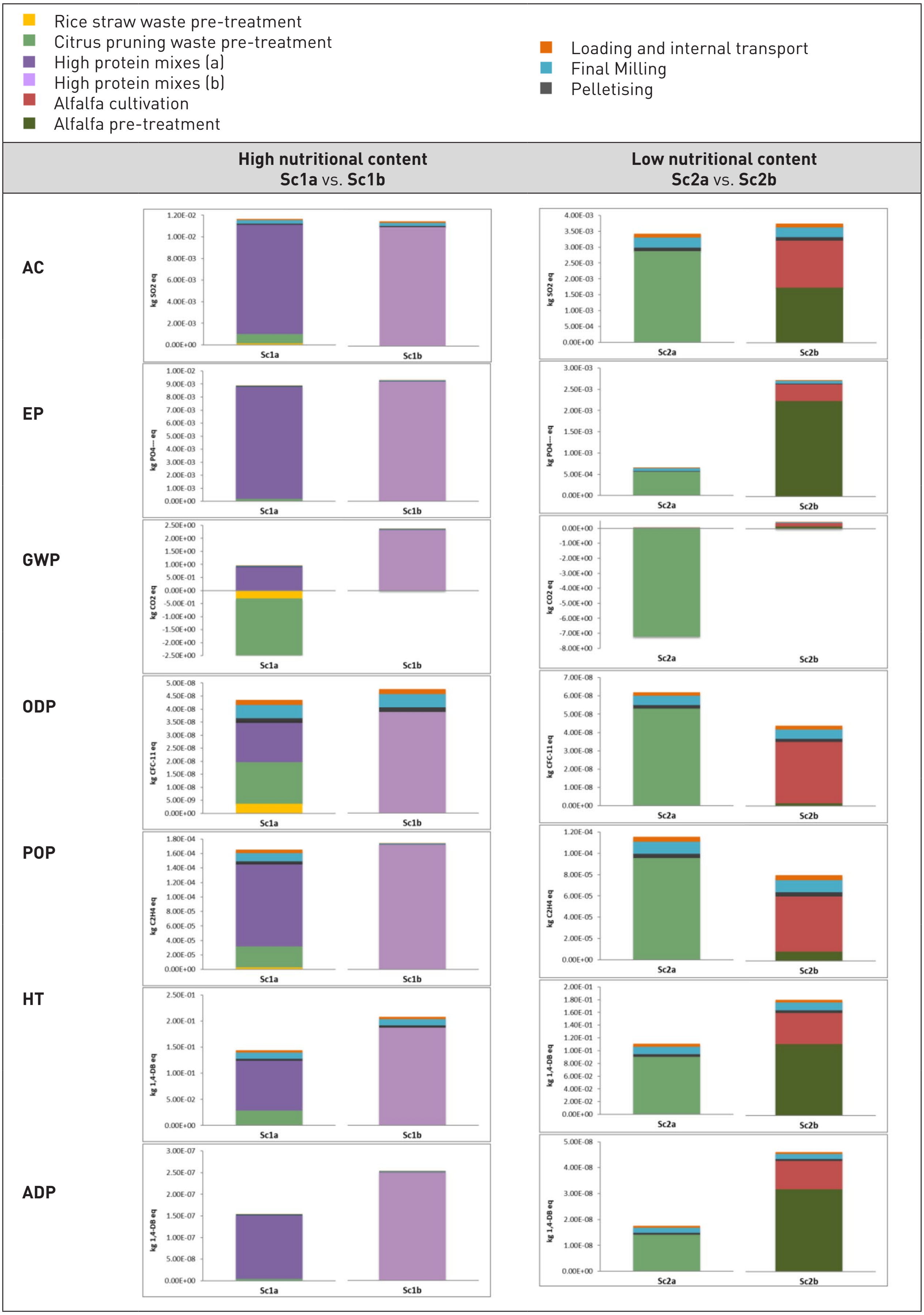

Figure 3. Contribution made by each stage of the animal feed production to each impact category for each type of scenario.

Declaration of conflicting interests

The authors declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Funding

The authors disclosed receipt of the following financial support for the research, authorship, and/or publication of this article: This study has been supported by project LIFE16 CCM/ES/000088 (Life LowCarbon Feed).

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Supplemental material

Supplemental material for this article is available online.

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