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A clustering approach to analyse the environmental and energetic impacts of Atlantic recipes - A Galician gastronomy case study

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ABSTRACT

The definition of the term gastronomy encompasses both the knowledge of food and its handling, preparation and consumption. Beyond a sense of cultural identity and tradition, gastronomy also represents a pole of tourist attraction. This is the case of Galicia, a region in north-western Spain. Within this framework, local dishes, which include distinctive elements of the Atlantic diet, have gained popularity. This research delves into the sustainability of 60 Galician recipes by performing a hierarchical cluster analysis to study their carbon footprint, the energy return on investment ratio and cost.

The life cycle assessment methodology was followed to account for the carbon footprint and the energy return on investment ratio of the recipes. The scope was bounded to the cradle-to-fork phases through the life cycle: production of the ingredients, transport, and meal preparation. The functional unit selected was one serving of a Galician meal.

The results suggest that the recipes could be classified into three main groups according to the presence of a greater or lesser amount of animal-based products. Cluster 1 comprises 10 meat recipes. Cluster 2 encompasses 31 recipes rich in fish with some vegetables and moderate consumption of red meat and dairy products. Cluster 3 includes 22 vegetable-based recipes. The higher the portion of animal products in the recipes (mainly red meat), the higher the costs and carbon footprint and the lower the energy return on investment ratio. Conversely, plant-based recipes tend to reduce greenhouse gases emissions and increase cost competitiveness and energy efficiency indicators.

Based on this study, the food service could promote eco-labelling that support and certify restaurant menus. This research could also provide transformative climate education for sustainable food for consumers, giving advice to improve food-based dietary guidelines in Spain.

1. Introduction

The definition of the term gastronomy encompasses both the knowledge of food and its handling, preparation and consumption. In the midst of food globalization, it is necessary to preserve those unique elements that ensure compliance with the basic principles of a healthy diet in a global context of gastronomic heritage, nutritional quality and environmental preservation. Consequently, food products and services

Abbreviations: FBDGs, Food-based dietary guidelines; CF, Carbon footprint; EROI, energy return on investment ratio; GHG, greenhouse gases emissions; NAOS Strategy, Strategy for Nutrition, Physical Activity and the prevention of obesity; NRD9.3., Nutrient rich diet index; LCA, Life Cycle Assessment; CED, Cumulative Energy Demand; SDGs, Sustainable Development Goals.

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with low impact on the environment must contribute to the achievement of sustainable tourism (Chiang and Sheu, 2020), involving visiting food producers, restaurants, hotels, tour guides and local businesses (Mehul Krishna Kumar, 2019).

Within this context, actions have been developed to foster sustainable diets and eating habits. At global level, the EAT-Lancet diet is a global planetary healthy diet. This diet emphasizes the consumption of fruits, vegetables, whole grains, legumes, nuts and unsaturated oils. It also requires a significant reduction in consumption of red meat, sugar and refined grains (Willett et al., 2019). At national level, some current food-based dietary guidelines (FBDGs) have integrated nutritional, health and sustainability considerations (FAO, 2021). At regional scale, adherence to traditional patterns has demonstrated advantages for the environment, health, and culture of the region. This is the case of the well-known Mediterranean (González-García et al., 2020b) or the New Nordic diets (Mithril et al., 2012). The Atlantic diet, typical of the regions of Northwest Spain and Northern Portugal, was also included within this group of traditional diets (Esteve-Llorens et al., 2019).

Galicia, a region in northwestern of Spain, is framed within the Atlantic dietary pattern, which is characterized by the consumption of locally grown, seasonal and food products prepared with simple cooking processes to ensure the best flavor and aroma of the dishes. The range of products includes fruits, vegetables, bread, cereals and pulses, as well as fresh fish and seafood and dairy products. Olive oil is widely used for cooking and seasoning, fried foods are avoided, and consumption of meat is moderate with recommended weights per serving of 58 g for eggs, 112.5 g for lean meat and 55 g for fat meat (Calvo-Malvar et al., 2016). However, in recent decades, Galician cuisine is moving away from recommendations evolving towards globalized diets rich in meat, pre-packaged foods, refined sugars and out-of-season foods. Therefore, it is very important the adherence to and knowledge about the Atlantic dietary pattern in order totally exploit their potential.

In Galicia, cultural tourism with special mention of the "Camino de Santiago", is combined with gastronomic and oenological tourism (Xunta de Galicia, 2021). As a result of this gastronomic heritage, a hospitality industry in Galicia has grown having more than 21 thousand establishments, of which 90.7% correspond to the catering sector. In 2018, this business group had a turnover of 4768 million euros, which represented 4.5% of regional wealth (Hostelería de España, 2019). Due to its significant role in the Galician business fabric, the empowerment, sustainable growth, the improvement and competitiveness and the internationalization of the Galician food sector are key issues.

Despite the growing importance of gastronomic tourism in Galicia, there is scarce information to date on environmental impacts and nutritional dimensions of traditional recipes, with only some life cycle assessments of typical complete daily menus of the Atlantic region (Esteve-Llorens et al., 2019; González-García et al., 2021). Ensuring the market position of Galician food companies requires the incorporation of multi-criteria analysis in the food industry. The aim of restaurant management should be to implement green and energy-boosting regional dishes at affordable prices.

The carbon footprint (CF) has been used as an environmental indicator to evaluate carbon emissions associated with tourism activities (Lenzen M. et al., 2018). Previous studies estimated tourism produced about 8% of the global CO_2 emissions. Therefore, the carbon footprint can be used as a metric to evaluate cooking recipes within the Galician's food tourism following the path already begun by other authors, such as Schmidt Rivera and Azapagic (2019), who evaluated the environmental burdens of ready-made meals recipes or Kolbe (2020), who analysed the CO_2 emissions of cooking vegan, ovo-lactovegetarian or meat-containing recipes in Germany. Moreover, the energy return on investment ratio (EROI), a highly used indicator, could be provide information on the energy dimension (Laso et al., 2018b; Vázquez-Rowe et al., 2014). Finally, considering that monetary variables can also affect food choices (Green et al., 2013), a costing index could be calculated for each traditional Galician recipe (MAPA, 2019).

To deal with these multivariate issues, it was considered the appropriateness of multicriteria analysis. Addressing multicriteria analysis for the high number of recipes requires the need for multivariate mathematical-statistical methods. Hierarchical cluster analysis and the resulting dendrograms are a widely used branch in many domains of scientific literature, including the food sector (Bodor et al., 2021; Granato et al., 2018) and could be used as a simple way of grouping the recipes through their similarities (Wilks, 2011). Although research to date has not employed cluster analysis for assessing the sustainability of recipes, the hierarchical cluster analysis has been used to analyse the chemical composition of foods sold at restaurants (Da Silva Torres et al., 2006). Moreover, other statistical analysis, such as the data envelopment analysis, have been used to measure the level of sustainability of recipes (Chiang and Sheu, 2020).

With this approach to the problem, this work is expected to provide a solid basis on which consumers and food service can decide which type of recipes should be supported in order to fight climate change, low-energy and low-cost food, ensuring the quality, traceability and green sustainability of the Galician gastronomy. Thus, the aim of this study is to determine the environmental, economic and energetic sustainability of 60 Galician gastronomy recipes following a farm to fork strategy, which considers production, processing and consumption stages. With this purpose, multivariate analysis was applied as a mathematical tool to define hierarchical dietary clusters based on the greenhouse gases (GHG) emissions, the cost, and the EROI indicator of recipes.

2. Materials and methods

2.1. Meal recipes

Meal recipes were obtained from the recipe book Platos y Menus Atlánticos (Atlantic Dishes and Menus), based on the use of typical Galician food products. This book was published in the framework of the GALIAT project, the first clinical trial to study the effects of the Atlantic dietary pattern on metabolic and cardiovascular health and adiposity (Calvo-Malvar et al., 2016). It includes recipes nutritionally balanced by a team of nutritionists and information to guide weekly menu planning. Meal recipes and ingredients were detailed in **Tables SM1.1-SM1.5.** in the Supplementary Material.

The book is divided into five sections with different dishes: first course, divided into two subgroups (high-calorie and low-calorie), main course, also classified into two subgroups (high-calorie and low-calorie) and desserts. The daily menu should offer a first course (high-calorie), a main course (low-calorie) and a dessert. Another possibility is a first course (low in calories), accompanied by a main course (high in calories) and a dessert. The dessert should preferably be fruit and one or two days a week, a dairy. Processed desserts should be consumed only occasionally due to their high caloric value.

2.2. Calculation of impact indicators

2.2.1. Carbon footprint

The functional unit in this study is one serving of a Galician meal calculated from a cradle-to-fork approach, which includes three life cycle stages within the system boundaries: production of the ingredients (S_1), transport (S_2) and meal preparation (S_3).

- Production of the ingredients (S1): Production of the different food ingredients that constitute each recipe. Depending on the specific foodstuff, a cradle to farm or industry gate approach was followed at this stage.
- Transport (S2): Transport activities involved in the distribution of the different foodstuffs from the factory or farm gate to retailers, as well as, from the retailers to households. Special attention was paid in this stage to the origin of the different ingredients that constitute

the recipes. Food waste in the wholesale and retail distribution was considered.

- Meal preparation (S3): This stage includes the main cooking methods used to prepare the recipes (boiling, frying, baking), and refrigerator storage. Food waste in households was taken into account.

Fig. 1 displays an overview of the system boundaries considered in the LCA. Food waste and losses along the supply chain were included in the system boundaries. Therefore, quantities greater than those reported in the recipes will be produced for each ingredient. To calculate the net amount of food needed to prepare the meal, the percentages of waste at the wholesale and retail distribution stage (Gustavsson et al., 2013) and the average ratios of food waste in households (Garcia-Herrero et al., 2018) were taken into account.

The CF associated with the production of the different ingredients considered in the recipes was collected from LCA studies referring to 1 kg of edible product. A compilation of the different LCAs considered for the estimation of GHG emissions from the ingredients of each meal preparation was gathered in **Table SM1.6.** in the Supplementary Material. Priority was given to cradle-to-farm, cradle-to-industry, or cradle-to-port gate LCA studies. When additional life cycle stages were identified (cradle-to-grave, cradle-to-retailer or cradle-to-consumer), these have been removed from the CF calculation. On the other hand, local (Spanish) LCA studies on food production were chosen if available. If no LCA from peer-reviewed journal articles were accessible in the Spanish or the European framework, an average global result was taking into account based on systematic literature reviews and meta-analysis.

For each ingredient, the GHG emissions associated with transport activities from the production site to the consumer were calculated according to the following assumptions. For food ingredients produced in Galicia, road freight was considered for an average distance of 60 km. For all food products imported from outside Galicia but within Spain, an average distribution distance of 400 km was assumed (Esteve-Llorens et al., 2019). The fieldwork in the analysis of product labeling was fundamental to establish the food origin. The selected transport vehicle was a Euro 5 diesel freight truck (>32 tons) (Castañé and Antón, 2017). Its associated GHG emissions, 92.10 $mgCO_2eq \cdot kg^{-1} \cdot km^{-1}$, were obtained from the Ecoinvent ® v3.2 database and the IPCC characterization factors.

Food preparation also contributes to total GHG emissions due to the energy requirements for the different cooking techniques (e.g., boiling, frying or baking), calculated according to the methodology reported by Sonesson et al. (2003). The energy values were converted into kg CO_2 equivalent using the emission coefficient 0.45 $kgCO_2eq \cdot kWh$ provided by the Ecoinvent® database.

2.2.2. EROI

EROI expressed at percentage can be defined as the ratio of total energy produced to the amount of energy consumed in a production process (Bajan et al., 2021) as can be seen in Eq. (1).

$$EROI = \frac{Meal\ energy\ provided}{Cumulative\ Energy\ Demand} \cdot 100 \quad (1)$$

The Cumulative Energy Demand (CED) was estimated for each recipe. The CED data for each food product were collected from a number of existing LCA publications and SimaPro v9.0 software (**Table SM1.7.** in the Supplementary Material). The functional unit and system boundaries considered were those of the CF assessment. The energy provided by each recipe was calculated using DIAL (Ortega et al., 2016), a software tool for dietary assessment and nutritional analysis.

2.2.3. Cost

Assessing the economic dimension of recipes is fundamental to ensure food safety. The theoretical cost of each recipe was estimated by multiplying the gram quantities by the cost per quantity of each ingredient used in the recipe formula. The national single prices for each food ingredient were obtained from the Household Consumption Database Program (MAPA, 2019) The most updated data prices were used. For more details, see **Table SM1.8.** in the Supplementary Material.

2.3. Statistical analysis. Cluster analysis

A useful integration of the three indicators in a comprehensive comparison between recipes can be achieved by an agglomerative hierarchical clustering analysis. The algorithm starts by declaring each of the n recipes as a single cluster. In the first step, the two most similar recipes are merged to form one cluster giving in all n-1 clusters. In the second step, the two most similar clusters are merged to form one cluster, giving in all n-2 clusters. The iterative process is repeated until all recipes are merged into the same cluster occurring in step n-1 (Bergman and Magnusson, 2001).

To calculate the dissimilarity between two recipe clusters, Ward's minimum variance method was chosen because it was found to be the most suitable as it creates a small number of homogeneous and interpretable clusters with relatively more recipes. In addition, Ward's minimum variance method was found to outperform other hierarchical methods in general (Punj and Steward, 1983). The data pre-treatment method used in this work was autoscaling, which used the mean and the standard deviation for standardisation (Moreda-Piñeiro et al., 2001).

The result was presented in a dendrogram, a plot that graphically shows the organization of the recipes and their relationship in the form

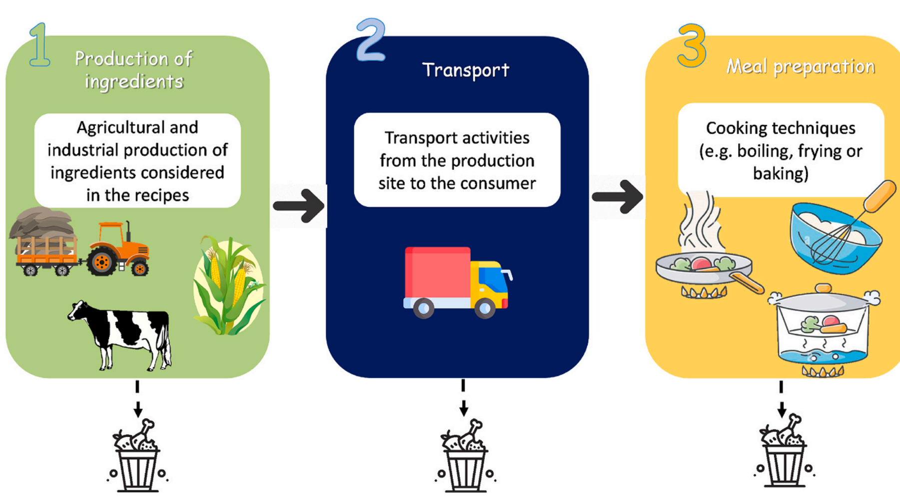

Fig. 1. System boundaries considered in the life cycle assessment.

of a tree (Granato et al., 2018). A constant height cut-off method was applied to identify three main clusters and eight secondary clusters, which are known as subgroups. The statistical software package R was used to perform the clustering analysis and generate the dendrogram.

3. Results and discussion

3.1. Estimated carbon footprint, EROI and cost of Galician recipes and comparison with the literature

This study reports the CF of more than 60 recipes of Galician gastronomy using LCA data. The CF associated with the different recipes was shown in Table 1. The production of raw materials was the main hotspot for global warming for all recipes. The effect of distribution activities remained insignificant regardless of the recipe (between 1% and 2% of the total CF). The rationale behind this finding was the consumption of proximity food ingredients and the short delivery distances associated with them. GHG emissions associated with cooking appliances were notable for some recipes involving different cooking methods (frying, boiling, baking), although on average, cooking activities were not the key factor in ranking recipes in terms of CF, which is in agreement with the results of other studies based on the Atlantic dietary recommendations (Esteve-Llorens et al., 2019; González-García et al., 2020a). The huge differences in GHG emissions of the different recipes could be explained as a function of the composition of animal-derived ingredients, mainly meat ingredients. The fact that meat-containing recipes led to higher emissions reflects the results of other researchers such as Berners-Lee et al. (2012), Rivera and Azapagic (2019) and Scarborough et al. (2014).

Recipes that contained meat implied a higher cost compared to other recipes (Table 1). In line with this, Kolbe (2020) found that meat-containing recipes on average lead to higher costs than ovo-lactovegetarian and vegan recipes in Germany. The price of milk-derived ingredients, such as cheese or butter, could be the reason for the high cost of other Galician recipes (MAPA, 2019). Moreover, favoring plant-based diets over resource-intensive animal-based diets not only reduces the cost of menus, but also implies a substantial opportunity, as reported in Shepon et al. (2018), who estimated that replacing animal products with plant-based foods in U.S. diets could feed 350 million more people.

The EROI results allow us to delve deeper into the energy efficiency of the Galician gastronomic sector, showing that recipes of animal origin, mainly meat-based, presented the lowest EROI values (see Table 1). Our results are in agreement with previous studies available in the literature. Therefore, Pelletier and Tyedmers (2011) showed an eightfold difference between animal- and plant-based food products in terms of energy efficiency. Following the same line of research, Laso et al. (2018a) found that the minimum EROI was observed for animal-based products such as eggs, meat, fish and seafood products.

3.2. Recipe classification by cluster analysis

The present research applied Ward's minimum variance cluster using the environmental, economic and energy indicators identified in the previous section as input variables. As a result, a classification of recipes was identified. Figs. 2–4 show the results and allow to study in detail the similarities and dissimilarities among the recipes. The results revealed a very large range in the CF, EROIs and costs among the three main clusters. The segment with the highest CF and cost was Cluster 1. The segment with the highest EROI was Cluster 3. Each cluster was further divided into more subtypes, as detailed below. The dendrogram, generated by the statistical software package R, is shown in Fig. 5.

3.2.1. Cluster 1

Of the total 63 meal recipes, this cluster included 10 recipes (Fig. 2) that have the characteristics of very low EROI with a mean and a

Table 1
Carbon Footprint (CF) (kg CO_2 eq), energy return on investment ratio EROI (%) and cost (€) of Galician recipes.

Meal	CF	EROI	Cost
First courses (high energy)			
Turnip greens and rice soup	5.23	4.8	5.92
Mashed turnip greens and potatoes	0.67	20.7	0.66
Cannelloni with vegetables and cream cheese	1.48	10.9	1.12
Potato and turnip greens salad	0.44	90.5	0.53
Lentils with turnip greens	4.25	9.6	5.27
Turnip soufflé	0.68	38.1	0.48
Fideuá with spinach and tomato sauce, tooped with cheese gratin	1.63	14.0	1.85
First courses (low energy)			
Beans with turnip greens	1.65	12.8	2.00
Tuna salad	0.36	20.3	1.33
Grilled tuna with Galician "zaragallada"sauce	0.55	27.9	1.47
Grilled squids with boiled potato	1.15	9.0	1.07
Beans with mussels and prawns	1.27	20.2	1.41
Mussel fideuá	0.94	23.1	1.24
Atlantic horse mackerel fillet	0.39	23.6	1.21
Bonito and vegetable salad	1.03	51.4	0.97
Lentil salad with turnip greens	0.36	72.4	0.58
Pork tenderloin with salad	0.96	25.0	1.24
Mussels marinara	0.44	17.1	0.69
Mussels in garlic sauce	0.39	38.6	0.59
Mussels with onion	0.48	17.3	0.72
Spanish Tuna Stew	1.05	26.4	1.86
Mussel pie	0.82	22.5	0.63
Scrambled eggs with mussels	0.50	21.1	0.47
Mussels Vinaigrette	0.36	24.8	0.69
Noodles with mussels	0.52	40.0	0.56
Omelet with turnip greens	0.41	39.4	0.39
Galician "zaragallada" sauce with poached egg	0.37	38.59	0.26
Main courses (high energy)			
Tuna with white rice	0.65	38.4	1.30
Mackerel with turnip greens and potatoes	0.51	50.3	0.87
Beans and rice	2.97	12.4	3.72
Pan-fried hake with lemon, potatoes and salad	0.95	19.5	1.28
Chickpeas with mussels	0.41	61.0	0.56
Cod and Potato Stew	0.49	25.4	1.98
Beef stew with potatoes and vegetables	4.69	11.0	3.66
Mussels and turnip greens lasagna	1.12	20.9	0.89
Lentils with turnip greens and rice	4.44	7.0	5.38
Hake in green sauce with potatoes	1.11	22.1	1.32
Chickpea stew with turnip greens	3.12	10.2	3.62
Galician-style octopus with potatoes	1.69	8.6	2.19
Turnip greens and ham quiche with cream cheese	1.25	13.0	0.96
Creamy mussel risotto	1.17	16.3	1.48
Fish stew with turnip greens	1.43	17.9	2.16
Main courses (low energy)			
Rice and turnip greens with tomato sauce and bechamel	0.67	38.9	0.46
Rice with carrots and tomato sauce	0.26	118.6	0.22
Turnip greens cream	2.99	3.1	3.81
Carrot, leek and potato cream	1.60	8.4	1.95
Pickled mussels with vegetables	0.40	33.9	0.51
Spanish Vegetable Stew	0.46	57.5	0.66
Pumpkin Ratatouille	0.31	20.0	0.84
Scrambled Eggs with turnip greens	0.39	39.4	0.40
Sautéed turnip greens with ham	0.46	51.2	0.58
Chicken noodle soup	3.19	3.4	3.96
Julianne soup	2.40	5.4	2.91
Garlic soup	4.00	6.2	4.76
Stuffed tomatoes with turnip greens	0.70	13.4	0.57
Tuna and tomato toasts	0.71	81.0	0.59
Desserts			
Rice pudding and mirabelle plum	0.58	31.1	0.18
Mirabelle plum cake	0.40	28.0	0.22
Mirabelle plum brownie	0.38	19.5	0.18
Mirabelle plum fritters	0.18	50.5	0.11
Mirabelle plum fried milk	0.19	39.8	0.17
Mirabelle plum soufflé	0.51	31.8	0.30
Cream cheese soufflé	0.72	17.1	0.42

Fig. 2. Recipe classification based on carbon footprint (kg CO2 eq) (green), energy return on investment ratio EROI (%) (blue) and costs (€) (yellow) – Cluster 1.

Fig. 3. Recipe classification based on carbon footprint (kg CO2 eq) (green), energy return on investment ratio, EROI (%) (blue) and costs (€) (yellow) – Cluster 2.

standard deviation of 7.3 ± 3.3 combined with very high carbon intensity (3.7± 0.9 kg CO_2 eq) and economic cost (4.3 ± 0.9 €). These recipes tended to have characteristics of high-carbon lifestyle factors, such as meat-rich ingredients. Meals in this cluster contain high portions of beef broth. Some recipes also include other types of red meat (pork, sausage, ham) as well as white meat (chicken). This close association between meat and CF is in line with the findings reported by González-García et al. (2021), which showed a wide variation in GHG emissions in menus for toddlers based on the Atlantic dietary guidelines in relation to the presence of animal-based foodstuffs, specially beef.

The dendrogram allows us to identify a major division of this cluster into two subgroups according to the contribution of meat to the recipe. The first subgroup consists of six main course recipes: julienne soup, turnip green cream, chicken noddle soup, chickpea stew with turnips. It contains preparations with a meat content of more than 85 g.

The second subgroup, consisting of three main courses (Beef stew

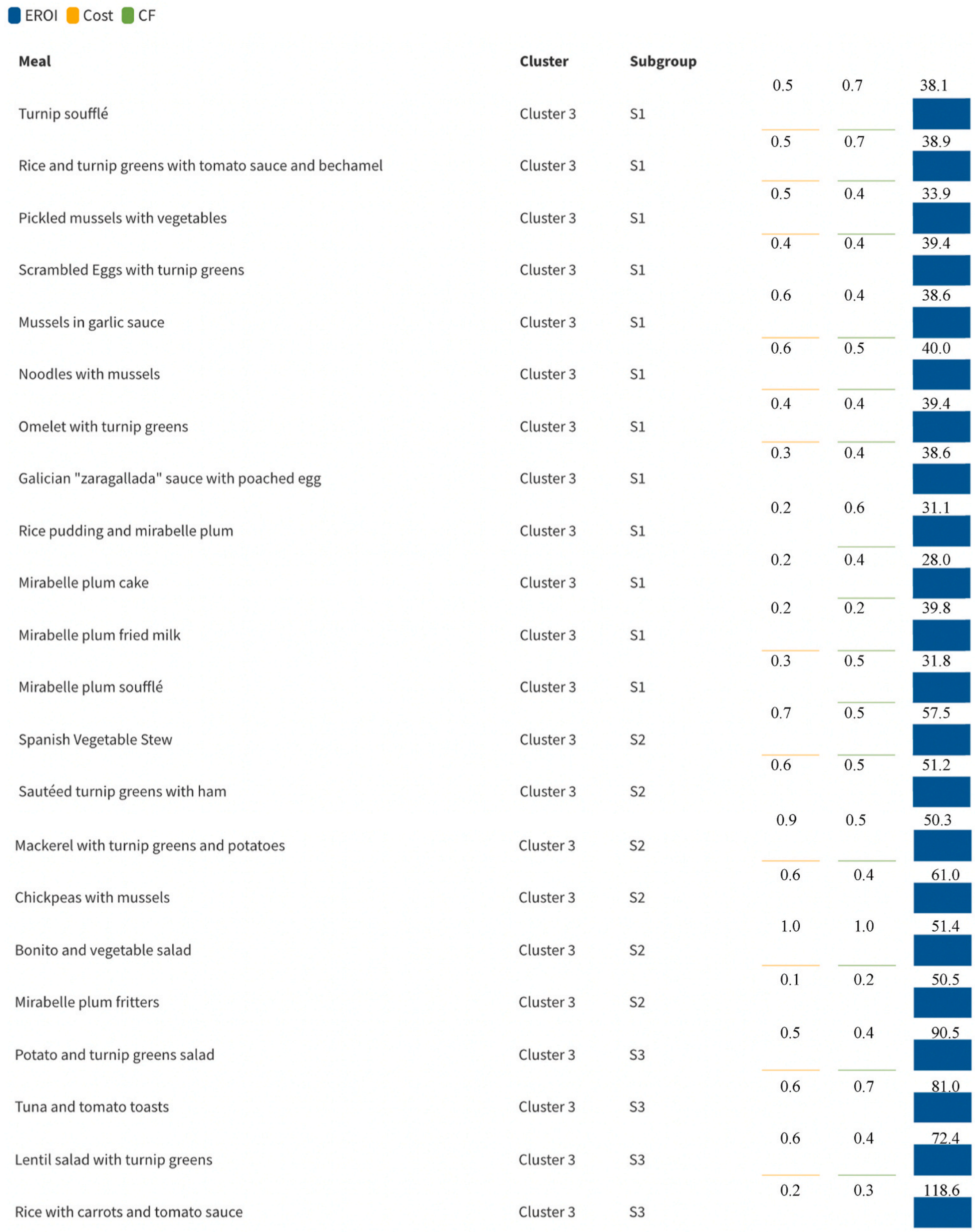

Fig. 4. Recipe classification based on carbon footprint (kg CO2 eq) (green), energy return on investment ratio EROI (%) (blue) and costs (€) (yellow) – Cluster 3.

with potatoes and vegetables, garlic soup and lentils with turnip greens and rice), and two first courses (Lentils with turnip greens and turnip greens and rice soup), is prepared with meat portions ranging from 161 to 204 g.

3.2.2. Cluster 2

There are 31 meal recipes in cluster 2 (see Fig. 3). Fewer high-carbon lifestyle characteristics are observed in this cluster compared to cluster 1. Recipes rich in fish with some vegetables and moderate consumption of red meat and dairy products were included in this second cluster, which can be divided into three subgroups.

Subgroup 1 consists of meals with little meat, octopus and meals with plenty of fish. The average CF, EROI and cost for this subgroup were in terms of mean and standard deviation of 1.6 $\pm$ 0.1 kg CO_2 eq, 12.4 $\pm$ 4.0 and 2.0$\pm$ 0.1 €, respectively. This subgroup includes three main courses (Galician-style octopus with potatoes, fish stew with turnip greens, carrot, leek and potato cream) and two first courses (beans with turnip greens and fideuá with spinach and tomato sauce topped with cheese grain).

Subgroup 2 consists mainly of moderate fish and seafood recipes, including different types of fish species (hake, cod, tuna, mussels, prawns, squids, mackerel and fish soup). The fish-based dishes included in this subgroup are: cod stew with potatoes; lasagna of mussels and turnip greens; hake in green sauce with potatoes; creamy mussel risotto; tuna salad; grilled tuna with Galician “zaragallada” sauce; grilled squid with boiled potatoes; beans with mussels and prawn; mussel fideuá; Atlantic horse mackerel fillet; tuna stew; tuna with white rice; fried hake with lemon, potatoes and salad. Some dishes are rich in dairy products, mainly cheese, such as turnip and ham quiche with cream cheese or cannelloni with vegetables and cream cheese. This subgroup 2 contains nine first courses and five main courses. The recipes in this subgroup have an average carbon footprint and a standard deviation of 0.9 $\pm$ 0.3 kg CO_2 eq, an EROI of 21.4 $\pm$ 7.1 and a cost of 1.3$\pm$ 0.3 €.

First course recipes for mussels constitute a large part of the recipes in subgroup 3 (mussels in marinara style, mussels with onions, mussel cake, scrambled eggs with mussels, mussels in vinaigrette). Cheese is

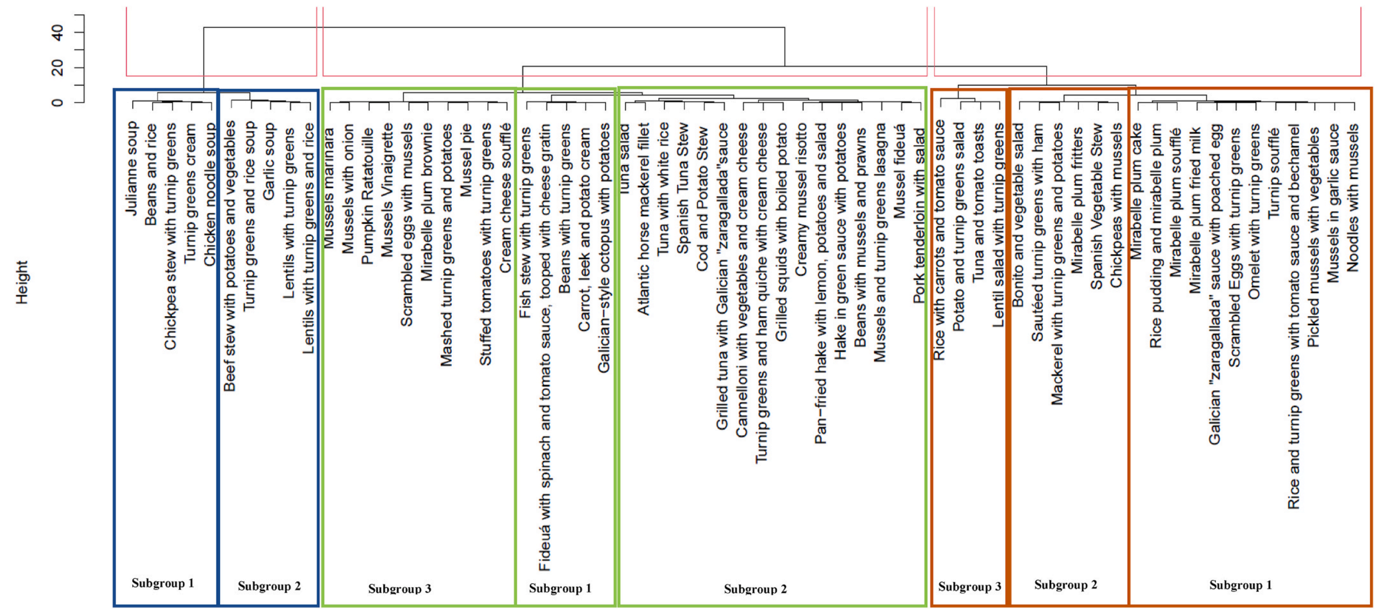

Fig. 5. Cluster dendogram.

used as an ingredient in moderate amounts (about 20–25 g) in some recipes included in this subgroup 3, such as turnip and potato puree, fresh cheese soufflé and tomatoes stuffed with turnips. The brownie dessert Mirabelle was also classified within this subgroup due to the high CED of cocoa (194.8 MJ) and sweetener (61.3 MJ). Although the average CF (0.5 ± 0.2 kg CO_2 eq) and the EROI (19.4 ± 3.2) was slightly lower than for subgroup 2, the most important distinction with subgroup 2 was in the monetary cost, being 0.6± 0.2 € for subgroup 3.

3.2.3. *Cluster 3*

The third cluster comprises 22 recipes (see Fig. 4), mainly of vegetable origin. Some products of animal origin with a relatively high CED (milk, tuna, mackerel, eggs, mussels) were less common ingredients, but were also part of some of the recipes in this group. The food preparations in cluster 3 contain the most low-cost (0.46 ± 0.22 €) and low-carbon (0.7 ± 0.18 kg CO_2 eq) recipes. Furthermore, this cluster could be divided into three subgroups based primarily on EROI values.

The first subgroup includes dishes with milk, eggs and fish (mussels and tuna) with EROI values ranging from 28 to 40. Dishes made with milk comprise four mirabelle dessert recipes (mirabelle plum rice pudding, mirabelle plum cake, mirabelle plum fried milk and mirabelle plum soufflé) and three turnip recipes (rice and turnips with tomato sauce and béchamel, turnip soufflé and scrambled eggs with turnips). The list of dishes with eggs contains two first courses (omelette with turnip greens and Galician “zaragallada” sauce with poached egg). Two first courses with mussels in small quantities (less than 75 g) were also included in this subgroup (mussels with garlic and pickled mussels with vegetables).

The second subgroup was based on vegetable dishes (vegetable stew, mirabelle plum fritters, sautéed turnip greens with ham) and three fish dishes with low CED (chickpeas with mussels, bonito and vegetable salad, and mackerel with turnip greens and potatoes). The EROI values ranged from 50.3 to 61.0.

The third subgroup are recipes based on vegetables, starch-based products (rice and bread), lentils and tuna. This subgroup consists of two first courses (potato and turnip greens salad, and lentil salad with turnip greens) and two main courses (tuna and tomato toasts, rice with carrots and tomato sauce). This subgroup has the highest EROI values, ranging from 72.4 to 118.6.

3.3. *Comparison with the literature: sustainable diets and recipes, and development of ecolabels*

The trend of promoting sustainable eating is growing in the literature and reflects in the catering industry, which offers interesting perspectives on the role of restaurants in the promotion of gastronomic heritage and sustainability. Therefore, environmental, nutritional and economic aspects have been analysed for different complete daily traditional dietary recommendations around the world.

There are recent results published for traditional eating habits, defined as a seasonally restricted and local food consumption. Therefore, Ulaszewska et al. (2017) used an environmental hourglass approach for the analysis of the GHG emissions of the New Nordic Diet. Other authors, such as González-García et al. (2020b) quantified the CF of the Atlantic Diet and the Mediterranean Diet considering a cradle-to-consumer gate approach and a functional unit based on daily food consumption. Cambeses-Franco et al. (2021) and Kovacs et al. (2021) examined the global warming impacts of FBDGs in Italy, Germany, India, the Netherlands, Oman, Thailand, Uruguay and United States. At global level, Kesse-Guyot et al. (2021) explored the environmental impacts (GHG emissions, CED and land occupation) associated with the EAT Lancet diet.

In the same line, to date very few studies have assessed nutritional, health and environmental sustainability of recipes. Hence, González-García et al. (2021) analysed the menus served at a Spanish nursery canteen considering two environmental indicators: CF and water footprint (WF). Both indicators for the menus varied considerably between 619 and 1359 L·menu^{-1} for the WF and 0.75–2.95 kgCO_2eq·menu^{-1} for the CF.

On the other hand, some studies jointly assessed environmental dimensions with nutritional ones. Batlle-Bayer et al. (2020) analysed the global warming potential, blue WF and land use of 15 tapas meals eaten in a Spanish restaurant. The novelty of the study carried out by Batlle-Bayer et al. (2020) was the choice of a functional unit based on the caloric energy intake and the nutritional quality of the meals. Ribal et al. (2016) developed a model to build nutritional, sustainable and economic diets. They chose as a case study a menu for school children in Spain. Rossi et al. (2021) designed a four-week menu characterized by large vegetable components using a mathematical model. This menu combined nutritional adequacy and acceptability criteria while minimized GHG emissions.

In line with these few multi-criteria sustainability studies, our research not only analysed the characteristics of the Atlantic diet and its environmental, energetic and economic sustainability, but also make their advantages visible among consumers and restaurants providing a basis for the introduction of ecolabels in restaurants enabling consumers to make informed purchasing decisions. Moreover, dietary patterns around the world could adopt some of the positive aspects of the Atlantic diet to improve their sustainability profile.

3.4. Policy implications

This work builds on the proposition that meals and menus with low impacts on the environment, low cost and high EROI can help enable sustainability food transitions, contributing to the achievement of green food service and generating positive experiences for all the concerned parties (e.g. local businesses, restaurants, consumers, tour operators) (Mehul Krishna Kumar, 2019).

Tourism activities make a relevant contribution to GHG emissions (standing at about 8% of the world's carbon emissions) (Lenzen et al., 2018). By 2035, it is estimated that emissions from tourism will increase more than double (UNWTO, 2020). The CF of tourism includes the GHG emissions associated with tourism activities (food purchase, accommodation, transport, fuel, and shopping). Due to the important role of tourism in Spain, the CF associated to it was estimated on 10.6% of total CO_2 emissions (Cadarso et al., 2015). This study addressed the need to reduce CO_2 emissions associated with tourism in Spain through the promotion of sustainable recipes.

We showed benefits for public health as well as potential positive environmental and economic implications if we reduce animal-based products in the recipes, especially red meat. These conclusions are useful to improve the healthy Atlantic dietary pattern in relation to its environmental sustainability. However, we need potential pathways for materializing these transitions towards more plant-based diets, advances in policy-making and stakeholder engagement.

Governments should formulate national guidelines, which contribute not only to personal health and nutrition, but also to local and global environmental sustainability. Out of 215 countries, only 83 have food-based dietary guidelines, with 20 including limited meat intakes. Their absence is more significate in low-income countries (Gonzalez Fischer and Garnett, 2016).

Public health nutrition strategies should also promote global reference diets such as the global dietary recommendations of the World Health Organization or the EAT-Lancet Commission on Healthy diets from Sustainable Food Systems (Willett et al., 2019). These diets will ensure compliance with the Sustainable Development Goals (SDGs) and the Paris Agreement. They should form the basis for educational programs and nutrition policies.

On the other hand, school meals can also help students, their families, and the broader community by offering nutritional education experiences. The recommendations on sustainability in school feeding policies and the sustainability practices adopted in schools have been widely addressed in the scientific literature (Dos Santos et al., 2022; Eustachio-Colombo et al., 2020). Moreover, food provides a useful vehicle for teaching cultural issues to school children. The incorporation of some of the sustainable Atlantic recipes analysed in this study in the schools meals would help to promote the Atlantic diet based on fresh, seasonal and local foods, and to reduce food-related greenhouse gases emissions. School garden programs are an excellent platform for experiential learning and nutritional education. School gardens are ideal for encouraging eating seasonal food and for promoting environmental attitude, traditional knowledge, and experience. These aspects help fulfill the potential of food in the achievement of sustainable development goals. Therefore, governmental funds should be inverted in these initiatives.

Finally, the development of alternative nutritious and healthy hybrid meat substitute products can potentially help to cope with climate change and take action for the SDGs. Due to the lower content of amino acid, vitamins and n-3 poly-unsaturated fatty acids in plant-based protein meat substitutes, more scientific research is needed in this field of study. Additional funding should be made available to academic research.

3.5. Assumptions and limitations

The constraints, limitations, and assumptions are relevant to address the potential shortcomings of the research. Carbon emissions and their impact on climate change are one of the main challenges for achieving environmental sustainability. Although other indicators to measure biodiversity loss and water issues may be of interest, the CF was chosen since is a good proxy for the rest of the impacts (Kalbar et al., 2017) and it is the most used indicator in the environmental analysis of recipes and diets (Kovacs et al., 2021; Batlle-Bayer et al., 2020).

The wide range of LCA studies used for the purpose of quantifying the potential CF of each recipe and the lack of uncertainty measurement results for each CF collected in the literature for each food ingredient did not allow for a sensitive and reliable uncertainty analysis. In addition, the CF of spices and seasonings were not taken into account (bay leaf, parsley, oregano, paprika, cinnamon) in the evaluation of the CF mainly due to the small quantities in which they are included in the recipes. For the same reason, the economic costs of spices and seasonings were also not considered in the economic study.

Moreover, we were assumed a distance of 400 km for all food products imported from outside Galicia but within Spain according with Esteve-Llorens et al. (2019). Although this assumption is very restrictive and favor some ingredients and disadvantage others, it does not significantly modify CF results. The rationale behind this is that distribution activities were not the main CF hotspot for any recipe. This fact had also already addressed in previous studies in the scientific literature (Esteve-Llorens et al., 2019; González-García et al., 2020a).

On the other hand, due to the lack of information on the EROI values of some food ingredients, some assumptions were made. Therefore, spices, condiments and beverages were excluded from the energy assessment. In addition, some food ingredients were assimilated to others of the same family. This applies to leek (assimilated as garlic), endive (assimilated as lettuce), turnip greens (assimilated as broccoli) and lentils (assimilated as chickpeas). A detailed description of these assumptions and limitations could be found in the Supplementary Material.

As for the hierarchical cluster analysis, the main limitation is that there is no objective way to establish the clusters found when cutting the branches of the dendrogram. We have used the most common method of constant height cutoff. However, there is controversy about the optimal cutoff parameter or how to estimate the number of clusters in the data set (Langfelder et al., 2008).

Regarding the database, it was considered as a reference a book that includes dishes that take part of the Atlantic Diet, although it is not an accurate representation of it. Despite this fact and in the framework of this study, the use of this recipe book is useful to respond to the main objective of this research, which is to make a general classification of recipes consumed in Galicia based on sustainability factors.

4. Conclusions

This study contributed to a better understanding of the environmental, economic and energy sustainability of food recipes belonging to the Galician gastronomy. The findings from this study revealed the classification of recipes into three meaningful clusters with significant differences in the CF, EROI and costs. It could be evidenced that this classification was linked to the greater or lesser presence of animal-based products in the recipes.

The study highlights that reducing animal-based ingredients in recipes not only leads to a pronounced reduction in GHG emissions, but also to low cost and high energy efficiency. In addition, replacing red meat with white meat, fish and seafood, and dairy is associated with a lower carbon footprint and higher cost-effectiveness. Although a team of nutritionists endorsed the nutritional quality of all recipes, it would be interesting to include the nutritional dimension in the selection criteria for future research, facilitating comparison between the nutritional quality of the recipes.

To sum up, findings from this study could be used as an educative tool for customers and restaurants to gain a more complete understanding of the environmental, economic and energetic impacts of recipes. On the other hand, they could also be used as a reference for the improvement of food based-dietary guidelines in Spain. Galician restaurants can benefit on this study creating environmentally friendly menus.

Ethical approval

This article does not contain any studies with human or animal participants performed by any of the authors.

Informed consent

All authors agreed with the content and all gave explicit consent to participate and publish.

Availability of data and materials

All data generated or analysed during this study are included in this published article [and its supplementary information files].

CRediT authorship contribution statement

Conceived and designed the experiments: C.C.-F., S.G.-G., G.F., M.T.M.; Performed the experiments: C.C.-F.; Analysed the data: All authors; Contributed materials/analysis tools: M.C-M, A.J. B-E, R.L., J.S.-C., F.G.; Writing of the original draft: C.C.-F.; Review & Editing: All authors.

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

All data used are available in the article

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jclepro.2022.135360.

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