



Assessment of the diet-environment-health-cost quadrilemma in public school canteens. an LCA case study in Galicia (Spain)

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Abstract

The role of policies and public school canteens as drivers of sustainable and healthy diets is increasingly becoming the center of attention of academics and policy-makers alike. This work therefore aims to assess the environmental, economic and nutritional quality dimensions of the menus consumed across the Local Network of School Canteens in the municipality of Ames (Galicia, Spain). It additionally performs different scenarios to evaluate the effects on the environment-cost-nutritional quality trilemma of implementing two major dietary changes in these menus: introducing more organic products, and shifting toward a more plant-based consumption pattern. To this end, this study considers the following indicators: a) those obtained from an energy and carbon life cycle assessment of the school menus (cradle-to-grave approach), mainly the cumulative energy demand (CED) and the carbon footprint (CF), complemented by some energy efficiency indicators; b) the total cost (TC) of the menus, obtained from their life cycle cost assessment (cradle-to-fork approach); and c) the nutritional quality of the menus, calculated and assessed based on the nutrient rich diet index (NRD 9.3). The CED, CF, TC, and NRD 9.3 index of a daily meal at school canteens are, respectively, estimated at 18.87 MJ, 1.30 kg CO₂-eq, EUR 4.65, and 278 per meal. The consumption of animal products and labor (for food preparation) are identified, respectively, as the main environmental impact and economic cost of the menus. The results of our research show how implementing changes in consumption habits toward a more vegetarian diet in school menus makes it possible to include organic products to generate the most positive effects in terms of the environment and nutrition without

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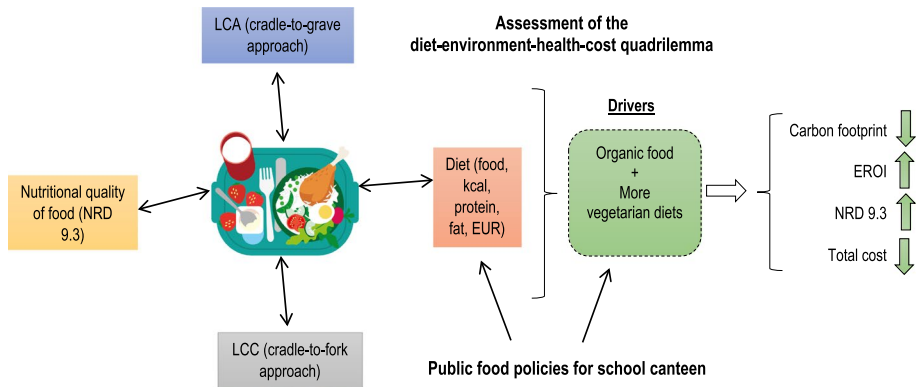
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incurring in cost overruns. Our work discusses the main barriers to be overcome and the political actions that must be enforced to advance the procurement of more sustainable and healthy public food.

Graphical abstract



Keywords Dietary change · Organic food · Vegetarian diet · Monetary cost · Nutritional quality · Public policies

Abberivations

| | |
|------|-----------------------------|
| CED | Cumulative energy demand |
| CF | Carbon footprint |
| EROI | Energy return on investment |
| GHG | Greenhouse gas |
| LCA | Life cycle assessment |
| LCC | Life cycle cost |
| NRD | Nutrient-rich diet index |
| TC | Total cost |

1 Introduction

The importance of promoting public policies within the context of the European Green New Deal (EC 2020) aimed at establishing and fostering consumption habits that meet and/or improve nutritional requirements while minimizing the environmental impact of the whole supply chain has been widely discussed (Wunderlich et al. 2018; Neto and Gama Caldas 2018; Bonanno and Mendis 2021). Dietary change is one of the major topics discussed in the literature, and it has served to identify the main hotspots in terms of nutritional quality and environmental impact (Castañé and Antón, 2017; Clark et al. 2018; Esteve-Llorens et al. 2019; Lopes et al. 2021). The introduction of organic or more sustainable products (Treu et al. 2017; Batlle-Bayer et al. 2019) and, most importantly, the dietary change associated to a lower intake of animal products are reportedly the main drivers when it comes to reducing the climatic stress of food consumption (Westhoek et al. 2014; Poore and Nemecek 2018; Fresán and Sabaté 2019). These discussions are particularly

important in connection to public school canteens, where the prevalence of unhealthy eating habits among children and/or adolescents has a strong impact on the health system (Wickramasinghe et al. 2017). Students who eat in schools are “captive consumers”, i.e., they cannot choose their menu; other people make decisions on their behalf. Thus, public food procurement has the potential to promote healthier diets with a lower environmental impact and becomes a driver in the process of shifting toward agrifood sustainability (Galli et al. 2014; Hyska et al. 2020). It should not be forgotten that public procurement of goods and services represents almost 20% of GDP, while the total social food service market that includes educational services enjoys a budget of EUR 82 billion (COM 2013).

Within this backdrop, public food policies implemented through direct government action and public food procurement are key (Kleine and das Graças-Brightwell 2015). Prior to the implementation of Directive 2014/24/UE, “the lowest price” was the main criterion in public purchase biddings. The economic dimension was the most important one in terms of supplying and managing school meals (Goggins and Rau, 2016; Filippini et al. 2018). The current norm poses no hindrance to the expansion of public procurement based on environmental and/or social criteria. Consequently, “the most economically advantageous bid” has now become the main criterion, which may include initiatives designed to safeguard public interests such as public health or the environment (Galli et al. 2014; Adjei-Bamfo et al. 2019). Despite the change in the norm and the new European reduction targets, the criteria for defining public food policies at school canteens lack clarity. The annual budget for school canteens is still an obstacle when managing students’ meals (Ribal et al. 2016), and the low-cost criterion still commonplace in numerous models is detrimental to quality (Lehtinen, 2012; Smith et al. 2016). Hence, the high price of organic products is considered one of the most important barriers to their purchase even though it is not the only one (Filho et al. 2019; Melovic et al. 2020). In other words, general criteria or recommendations (regarding seasonality, proximity, rotation, etc.) are established, but no thresholds or objectives are set concerning strong impact indicators (Galli et al. 2014; Cerutti et al. 2017). For instance, in the case of Spain, dietary guidelines have been developed for the design of school menus in consonance with the students’ developmental stage and nutritional needs, but they include no environmental sustainability guidance (Martínez et al. 2020).

Bidding criteria and the ultimate interpretation of the norm are specified at the regional level, so territorial adaptation is a key factor in the relative success or failure of public food policies and school diets (Kovacs et al. 2020; Wijesinha-Bettoni et al. 2021). In this sense, quantifying the environmental impact and nutritional quality of school menus in different regions should essentially serve as a guide to promote public nutrition models and structural public food policies designed to improve the quality and sustainability of children’s diets (Oostindjer et al. 2017; Batlle-Bayer et al. 2021). Life cycle assessment (LCA) is one of the most widely used methodologies to evaluate the environmental impact of school diets in relation to different functional units (meal, kilograms of food, kilograms of protein, kilocalories, etc.). In this sense, Table 1 summarizes the background. Saarinen et al. (2012) show how the choice of a specific type of protein made a difference to the environmental impact of school meals because the general consumption of animal products, and particularly that of red meat, represented the main hotspot (Jungbluth et al. 2016; Cerutti et al. 2017; Tregear et al. 2019). School meals low in salt, saturated fats and sugar are also associated with lower greenhouse gas (GHG) emissions and healthier food models (Wickramasinghe et al. 2016 and 2017). Other works have shown how meat-based menus—with chicken—may have a lower impact than plant-based menus rich in dairy products (De Laurentiis et al. 2017 and 2019). Studies like those of Benvenuti et al. (2016) and Ribal et al. (2016) have proposed models to optimize

Table 1 Main works analyzing and quantifying the relationship between diet, environment, health and monetary cost in school canteens using an LCA methodology

| Scope of the study | Countries | Boundaries | Functional unit | Evaluation | | | Reference |
|---|-------------|------------|--|--------------------------|-----------------------------|---------------------|---------------------------------------|
| | | | | Environmental assessment | Nutritional quality indexes | Economic assessment | |
| Home-made, ready-to-eat and school meals | Finland | F to W | Meal | CF and CED | No | No | Saarinen et al. (2012) |
| Assessment of daily school meals | Italy | F to W | kg of food consumed in one week | CED and CF | No | No | Caputo et al. (2014) |
| Optimization of school menus | Italy | F-P-T | Meal | CF and WF | No | No | Benvenuti et al. (2016) |
| Catering service (public or otherwise) | Switzerland | F to C | Meal | CF and Eco-points | No | No | Jungbluth et al. (2016) |
| Optimization of school menus | Spain | F to C | Plate of food | CF | No | Total cost | Ribal et al. (2016) |
| Nutritional evaluation of the Primary School Food Plan (SFP) | England | F-P | Meal | GHG emissions | No | No | Wickramasinghe et al. (2016 and 2017) |
| Primary school meals | England | F to W | Meal | CF and WF | No | No | De Laurentiis et al. (2017) |
| Evaluation of the catering service | Italy | F to W | Meal | CF | No | No | Cerutti et al. (2017) |
| Environmental assessment tool for school meals | England | F to C | Meal and kg of food, kcal and g of protein | CF and WF | No | No | De Laurentiis et al. (2019) |
| Assessment of the environmental and cost impacts of food consumption and wastage in school canteens | Italy | F to W | Meal | CF, PO, A and E | No | Total cost | García-Herrero et al. (2019) |

Table 1 (continued)

| Scope of the study | Countries | Boundaries | Functional unit | Evaluation | | | Reference |
|--|---------------------------------------|------------|----------------------------------|--------------------------|-----------------------------|---------------------|------------------------------|
| | | | | Environmental assessment | Nutritional quality indexes | Economic assessment | |
| Evaluation of different public food purchases | Croatia, Greece, Italy, Serbia and UK | F to W | Meal and kg of food | CF | No | Economic value | Tregear et al. (2019) |
| Nutritional recommendations in school canteen guidelines | Spain | F to C | Meal | CF | No | No | Martínez et al. (2020) |
| Assessment of the Mediterranean diet | Italy | F to C | Meal and 1000 kcal of total diet | CF and EF | No | No | Rosi et al. (2020) |
| Assessment of the environmental and cost impacts of food provided and wasted in a US school canteen | US | F to W | Meal | CF, PO, A and E | No | Total cost | García-Herrero et al. (2021) |
| Environmental and nutritional evaluation of low-carbon meals in schools | Spain | F to W | Meal | CF, CED, BW and LU | Yes | No | Battle-Bayer et al. (2021) |
| Evaluation of the climate change mitigation potential of different public policies for school canteens | Spain | F to W | Meal and kg of food | CF | No | No | Pérez-Neira et al. (2021) |

Table 1 (continued)

| Scope of the study | Countries | Boundaries | Functional unit | Evaluation | | Reference |
|---|-----------|------------|------------------------------|--------------------------|-----------------------------|--------------------------|
| | | | | Environmental assessment | Nutritional quality indexes | |
| Diet-environment-health-monetary cost quadrilemma associated with public food procurement | Spain | F to W | Meal, kg of food and protein | CED, CF and EROI | Yes | Total cost This study |

where F = farm, P = processing; T = transportation; C = consumption; W = waste; CF = carbon footprint; CED = cumulative energy demand; WF = water footprint; EF = ecological footprint; PO = photochemical ozone creation; A = acidification potential; E = eutrophication; BW = blue water; LU = land use.

the management and rotation of menus so that the nutritional and the environmental requirements are both met and reconciled. Likewise, the climatic effects of introducing organic along with seasonal and local products in the menu have been evaluated, as have those of other drivers (waste reduction, green energy use, adherence to the Mediterranean diet, etc.) (Cerutti et al. 2017; García-Herrero et al. 2021; Pérez-Neira et al. 2021; Rosi et al. 2020).

Very few studies on school canteens have analyzed the diet-environment-health trilemma (see Tilman and Clark, 2014) by linking environmental sustainability and human health through nutritional quality indexes and strong environmental impact indicators to evaluate school meals (De Laurentiis et al. 2019). For example, Batlle-Bayer et al. (2021) address the trilemma using different nutritional quality indexes to explore how low-carbon meals in school canteens have greater nutritional benefits. Despite the importance of the economic dimension in organizing menus (Abejón et al. 2020; Cambeses-Franco et al. 2021; Schreinemachers et al. 2018; González-García, 2018), not many studies have examined the monetary cost associated with school canteens (Ribal et al. 2016; García-Herrero et al. 2020, 2021). In fact, to the best of our knowledge, no precedents include the economic dimension of the trilemma, i.e., those that analyze the diet-environment-health-cost quadrilemma in public school canteens. This is the novel contribution of our work. The analysis of the quadrilemma enables us to obtain substantial results and rigorous scientific information (see graphic abstract summary) that can be used by decision-making institutions and social agents to reformulate public policies and decisions on school meals.

Consequently, the main objective of this paper is to analyze the environmental, economic and nutritional quality dimensions of the school diet through the menus served at public school canteens. To this end, we also perform different scenarios that allow us to evaluate the joint effects of implementing two important dietary changes at different levels on the environment-cost-nutritional quality trilemma: a) introducing more organic products in the school menus, and b) shifting toward more plant-based consumption patterns. We collected primary information from the Local Network of School Canteens in the municipality of Ames (Galicia, Spain), and used three internationally recognized analytical tools to perform the analysis. Firstly, we executed an energy and carbon LCA (cradle-to-grave approach) to assess the environmental dimension focusing on two impact categories: abiotic depletion (fossil fuels) and IPCC global warming potential (100y). In particular, we used three impact indicators: a) the cumulative energy demand (CED); b) the carbon footprint (CF) expressed in different functional units (meal, kilograms of food, kilograms of protein); and c) the energy return on investment (EROI). In terms of the economic dimension, we performed a life cycle cost (LCC) analysis (cradle-to-fork approach) to estimate the total cost (TC) of the school meals. Finally, we calculated and assessed the nutritional composition of the school menu using the nutrient rich diet index (NRD 9.3) to analyze nutritional quality. We have additionally discussed the main barriers and political actions that must be overcome and implemented in order to advance toward a more responsible public food procurement system that is also more committed to economic balance, public health and the environment.

2 Materials and methods

2.1 Case study

Galicia is an autonomous region in Spain with a population of 2.8 million. It is located to the northwest of the Iberian Peninsula. The population of primary school students in Galicia is represented by 120,000 children, most of whom (approximately 70%) (MEYFP, 2020) attend public schools. The annual regional budget for school canteens in these public schools is EUR 28.8 million (CEUFP, 2020). This study is based on primary information collected from the Local Network of School Canteens in the municipality of Ames (Galicia, Spain), which includes five public pre-school and primary education centers for children aged 3–12. Overall, these five schools provide approximately 200,000 meals per year, including first course, second course and dessert. This case study evaluates the environmental, economic and nutritional quality dimensions of the school canteen service in Galicia using three methodological approaches explained below: (1) an energy and carbon LCA (section 2.2); (2) an LCC analysis (section 2.3); and (3) the calculation and assessment of the nutritional quality of the menus based on the NRD 9.3 index (section 2.4).

2.2 Energy and carbon LCA of school menus

2.2.1 System boundaries, functional unit and data collection

The energy and carbon LCA of school canteens (cradle-to-grave approach) (ISO 2006) is carried out in five phases: (1) food production (in farm); (2) processing and packaging; (3) transportation; (4) food preparation (energy + auxiliary materials + labor); and (5) waste management. The two selected impact categories are abiotic depletion (fossil fuels), and the IPCC global warming potential (100y). The functional unit chosen is an average “meal”, constructed from the total amount of food consumed during the school year (2019) including first course, second course and dessert. We chose this functional unit because it is the most common one and allows us to compare it with previous studies (see Table 1). Kilograms of food and kilograms of protein are used as complementary functional units to express nutritional information in terms of LCA (Green et al. 2020).

Information about the following seven aspects was gathered and systematized to perform the energy and carbon LCA: a) consumption of food during the schoolyear (over 80 products); b) packaging; c) transportation (distances and means); d) consumption of final energy (electricity and other sources); e) materials used in kitchens and canteens (napkins, garbage bags, tableware, cleaning products, etc.); f) labor (cooking and serving); and g) waste management (organic and inorganic). Most of the information comes from in-depth inventories based on data provided by canteen managers through questionnaires as well as invoices paid throughout the schoolyear (a, d, e, f and g). With all of this information, we have generated a database of over 6,200 entries. The rest of the information (b and c) comes from secondary sources and/or estimates.

In terms of packaging (b), we weighted the plastic, cardboard, paper, glass and tin containers of the main products consumed at the school canteens to obtain an estimated total weight. In the case of transportation, average performances were assumed for both distances and means according to the information available for Spain. We used import and export data provided by the FAO (2020) to calculate the degree of food dependence per

product and drew the data on international distances and means of transportation from Pérez-Neira et al. (2016). As regards the food produced in Spain, the percentages of food-stuffs coming from Galicia and the rest of Spain were differentiated according to information from the inventories. When this information was not available, we defined the place of origin as the Spanish region having the largest production of that specific foodstuff (for instance, Andalucía was defined as the place of origin for olive oil). Using geographic information systems, we estimated the minimum distances traveled (place of production/processing–school), and we gathered information for the last phase of transportation (retailer–school) from the inventories, which included data on the monetary cost of fuel and the type of vehicle used for this purpose. Finally, we used food waste coefficients (Moreiras et al. 2005) to estimate waste management (f).

2.2.2 Calculation of environmental impact indicators

Three indicators are used to assess both abiotic depletion (fossil fuels) and the IPCC global warming potential: CED and CF, expressed in different functional units (meal, kilograms of food, and kilograms of protein), and EROI. We implemented the CML-IA baseline method (version 3.06) using SimaPro software and the Ecoinvent 3.5 and Agribalyse 3.0 databases to calculate these impact indicators. The information was completed with estimates for certain products from the literature (for instance, Clune et al. 2017). The total estimated CED and CF result from adding up the partial impacts of each of the above described subphases (Eq 1). Equation 2 is employed to adapt the total environmental impact to the corresponding functional unit. A subscript represents the impact indicators of functional units other than “meal” (for instance, CED_{food or protein}).

$$\text{TCED or TCF} = (EI_{\text{farm } (j-i)} + EI_{\text{packaging } (j-pi)} + EI_{\text{transportation } (ji)} + EI_{\text{school } (j-em)} + EI_{\text{waste } (j-w)}) \tag{1}$$

$$EI_{\text{farm } (j-i)} = \sum C_i \times \beta_{j-i}$$

$$EI_{\text{packaging } (j-pi)} = \sum P_{pi} \times \beta_{j-p}$$

$$EI_{\text{transportation } (j-ti)} = \sum C_i \times Km_{ti} \times \beta_{j-t}$$

$$EI_{\text{school } (j-em)} = \sum E_e \times \beta_{j-e} + \sum M_m \times \beta_{j-m}$$

$$EI_{\text{waste } (j-w)} = \sum (W_{wi} + W_{wm}) \times \beta_{j-w}$$

$$\text{CED or CF}_{\text{per f.u.}} = (\text{CED or CF}_{\text{per f.u.}}) / N \tag{2}$$

TCED = total cumulative energy demand (MJ); TCF = total carbon footprint (kg CO₂-eq); EI_{farm (j-i)} = environmental impact “j” (where “j” = CED or CF) of the production of foodstuff “i”, including the direct and indirect energy/emissions of inputs and capital; EI_{packaging (j-pi)} = environmental impact “j” of the packaging and container “p” (plastic, glass, tin, cardboard and/or paper) of foodstuff “i”; EI_{transportation (j-ti)} = environmental impact “j” of the distance traveled in means of transportation “t” (truck, ship and/or van) by foodstuff “i”; EI_{school (j-em)} =

environmental impact “j” of the consumption of final energy “e” (electricity, gas, diesel, etc.) and auxiliary materials “m” (napkins, tableware, etc.) in the schools; $EI_{waste(j-w)}$ = environmental impact “j” of the management of waste “w” (organic, plastic, glass, paper, tin, etc.); C_i = amount of foodstuff “i” consumed (kg); P_{pi} = amount of packaging “p” in foodstuff “i” (kg); Km_{ti} = kilometers traveled in means of transportation “t” by foodstuff “i” (km); E_e = amount of final energy “e” consumed in the schools (kwh or MJ); M_m = amount of materials “m” consumed in the schools (kg plastic, napkins, cups, cleaning products, etc.); W_{wi} = amount of waste “w” associated with foodstuff “i” (kg); W_{wm} = amount of waste “w” associated with, the use of materials “m” (kg); $\beta_{(j-i, j-p, j-t, j-e, j-m, j-wi, j-wm)}$ = impact coefficient “j” of foodstuff “i”, packaging “p”, means of transportation “t”, energy “e”, material “m” and type of waste “w” (MJ or CO₂-eq per functional unit); CED or CF_{per fu} = cumulative energy demand or carbon footprint per functional unit (meal, kg of food, or kg of protein); N = number of meals (No.), kilograms of food or kilograms of protein served during one year.

The EROI of school canteens was calculated (Equation 4) to analyze the energy efficiency of the school canteen model in relation to: i) the total energy of food, and ii) the energy that is actually socialized, i.e., that which is available for the students (total energy = socialized energy – waste). As for the EROI, the energy output was estimated from the energy contained in the food (Equation 3).

$$EO_{(total\ or\ socialized)} = \sum f_{(i)} \times \alpha_{(i)} \times L_{(i)} \tag{3}$$

$$EROI_{(total\ or\ socialized)} = EO_{(total\ or\ socialized)} / TCED \tag{4}$$

$EO_{(total\ or\ socialized)}$ = energy output (total or socialized) (MJ); $f_{(i)}$ = amount of foodstuff “i” consumed in one meal (kg); $\alpha_{(i)}$ = energy coefficient of foodstuff “i” representing the metabolizable energy of food (MJ per kg); $L_{(i)}$ = percentage of food waste from foodstuff “i” (%). The $EO_{(total)}$ was estimated considering that $L = 0$. The coefficients $\alpha_{(i)}$ and L were drawn from the nutritional study by Moreiras et al. (2005). $EROI_{(total\ or\ socialized)}$ = Energy return on investment (total or socialized) (MJ); TCED = total cumulative energy demand (MJ).

2.3 Life cycle cost of school menus

The total cost (TC) associated with school canteens was estimated using an LCC methodology (grave-to-fork approach) and resolving Equation 5 (adapted from Schmidt-Rivera and Azapagic, 2016). The TC includes the monetary cost of the food purchased, the energy and materials used in the school canteens, and the work performed during the process (cooking, serving, etc.). As in the environmental impact assessment, this information was collected from questionnaires and the purchase invoices kept by school canteen managers. An average meal was also chosen as the functional unit.

$$TC = \left(\sum C_{food(i)} + \sum C_{energy} + \sum C_{material} + \sum C_{labor} \right) / N \tag{5}$$

TC = total cost (EUR); $C_{food(i)}$ = monetary cost of purchasing foodstuff “i” (EUR), which includes the costs of producing, processing and transporting it; C_{energy} = monetary cost reflected in the energy invoices (EUR); $C_{material}$ = monetary cost of purchasing auxiliary

materials (EUR); and C_{labour} = monetary cost associated with the remuneration of the work carried out in kitchens and canteens (EUR); N = number of meals served during the school year (No.).

2.3.1 Calculation and assessment of the nutritional quality of the menus based on the NRD 9.3 index

Using information on the food consumed, we estimated the kilocalorie, protein, carbohydrate and fat intake per meal for each of the main food groups. We also used the nutrient rich diet index (NRD 9.3) designed by Drewnowski (2009) (see Equation 6) to assess the nutritional quality of the school diet. This index considers the daily consumption of nine nutrients that should be encouraged (proteins, fiber, calcium, iron, magnesium, potassium, and vitamins A, E and C), and another three that should be limited (total sugars, saturated fats and sodium). The greater the intake of the encouraged nutrients and the smaller the intake of those discouraged, the higher the score of the NRD 9.3 index. We estimated the NRD 9.3 index assuming that a school canteen menu is equivalent to 2,000 kcal per person and day to homogenize the results for comparative purposes.

$$\text{NRD9.3} = \sum_{i=1}^{i=9} \text{Nutrient}(i)/\text{RDV}(i) - \sum_{k=1}^{k=3} \text{Nutrient}(k)/\text{RDV}(k) \quad (6)$$

where nutrient (i) = protein, fiber, calcium, iron, magnesium, potassium, vitamin A, vitamin E and vitamin C; nutrient (k) = total sugars, saturated fats and sodium; RDV (i or k) = recommended daily value drawn from Drewnowski (2009). The complete nutritional composition of the foodstuffs has been obtained from the Spanish Food Composition Database (<https://www.bedca.net/>).

Seeking analytical consistency to link the nutritional quality of the food consumed in schools to the environmental and economic impact of the meals, we calculated the CED, CF and monetary cost of the food excluding the elaboration of school meals and waste management phase, i.e., from a cradle-to-school gate approach (section 3.2).

2.4 Dietary change scenarios

The average diet of school canteens in Ames served as the baseline scenario from which to build four other scenarios to assess the nutritional effects (kilocalories, proteins and NRD 9.3 index), environmental impacts (CED, CF and EROI) (cradle-to-grave approach), and economic consequences (TC) (cradle-to-fork approach) of two dietary changes: a) increasing the consumption of organic foodstuffs, and b) reducing the consumption of animal products to steer toward a more vegetarian diet. Table 2 summarizes the changes in the quadrilemma assessed in each of the proposed scenarios.

We implemented the above-described methodology and incorporated some additional estimates for organic products from the work of Pérez-Neira and Grollmus (2018) for vegetables and from Vitali et al. (2018) for veal, among others, to calculate the CED, CF and EROI for the different scenarios. For the TC, we took the average price per season (fall/winter and spring) of the different products, as provided by the Consello Regulador de Agricultura Ecolóxica (Galician Regulatory Council for Ecological Agriculture). The Consello is the official body in charge of regulating ecological agriculture in Galicia; it publishes weekly information on more than 900 products (fresh and processed). In some cases

Table 2 Description of the dietary change scenarios

| Drivers | Description of the scenarios |
|---|---|
| (S1) More organic products | Substitution of organic products (all products except for fish and bottled water) for 30% (S1a) or 60% (S1b) of animal products and conventional vegetables. From an environmental point of view, this scenario only affects the production phase, i.e., the supply chain remains the same, except for the production management. |
| (S2) More vegetarian diet | Substitution of vegetable products (more cereals, legumes, fruits and vegetables) for 30% (S2a) or 60% (S2b) of animal products (meat, fish, eggs and dairy products), attending to the nutritional recommendations of the Lancet Commission (Rockström et al. 2019). From an environmental standpoint, this scenario affects the production, packaging and transportation phases (given that certain foodstuffs are replaced by others). |
| (S3) More organic products and more vegetarian diet | A combination of S1 and S2: A 30% (S3a) or 60% (S3b) more organic and plant-based diet. The consumption of bottled water was excluded from this calculation. |
| (S4) Monetary balance | Maximum reduction of the impact and equal monetary cost (TC) in relation to the baseline scenario with only a 0% to 0.5% variation. |

(seasonal vegetables, meat, etc.), we also used the prices of the products sold by two of the main distributors of ecological products in Galicia, the Cooperativa Galega Daiquí and Verín Biocoop.

3 Results

3.1 Energy and carbon LCA and LCC analysis of public school canteens

Table 3 reflects the CED, CF and TC for each phase in the life cycle of the school menus. Thus, the CED was estimated at 10.87 MJ per meal, with associated average

Table 3 CED, CF and TC per meal provided in the school canteens

| LCA steps | CED MJ per meal | CF kg CO ₂ -eq per meal | TC EUR per meal | CED % | CF % | TC % |
|--------------------------|--------------------|--|--------------------|----------|---------|---------|
| A. Farm to school | 10.13 | 1.17 | 1.20 | 93.2 | 90.0 | 25.8 |
| 1. Farm | 5.47 | 0.94 | – | 50.3 | 72.3 | – |
| 2. Packaging | 1.16 | 0.07 | – | 10.7 | 5.4 | – |
| 3. Transportation | 3.50 | 0.16 | – | 32.2 | 12.3 | – |
| B. School to garbage bin | 0.73 | 0.14 | 3.45 | 6.7 | 10.8 | 74.2 |
| 4. School (a + b + c) | 0.81 | 0.08 | 3.45 | 7.5 | 6.2 | 74.2 |
| a. Energy | 0.65 | 0.06 | 0.06 | 6.0 | 4.6 | 1.3 |
| b. Auxiliary material | 0.16 | 0.03 | 0.35 | 1.5 | 2.3 | 7.5 |
| c. Labor | – | – | 3.04 | – | – | 65.4 |
| 5. Waste management | –0.08 | 0.05 | 0.00 | –0.7 | 3.8 | – |
| Total (1+...+5) | 10.87 | 1.30 | 4.65 | 100 | 100 | 100 |

emissions of 1.30 kg CO₂-eq and a total monetary cost of EUR 4.65. Farming is the phase with the largest environmental impact in terms of energy use and GHG emissions (around 50% and 72% of the total, respectively), followed by transportation (approximately 32% and 12% of the total). Food preparation and consumption is the phase with the lowest environmental impact (approximately 6% and 7%) (see Figure 1). The economic costs are asymmetrically distributed in relation to the environmental costs: While the cost associated with food (cradle-to-school gate) only represents 25% of the total, the cooking and serving of meals accounts for the remaining 75% (88% of which are labor costs). On the other hand, it is possible to observe how the management of waste allows for some energy savings (0.7%) through recycling and causes only 4% of the total GHG emissions. Table 4 shows the energy efficiency and energy intensity indicators for the school menus. Approximately 92% of the energy contained in the food is consumed by the students, while the remaining 8% is organic waste. As a result, energy



Fig. 1 Structure of (a) the nutritional composition and (b) the average environmental and monetary impact per meal (cradle-to-school gate approach) (%)

Table 4 Energy efficiency and energy intensity indicators per kilogram of food (cradle-to-grave approach)

| Indicators | Unit | Results |
|------------------------------|--|---------|
| CED_{food} | MJ per kg of food | 15.36 |
| CED_{protein} | MJ per kg of protein | 393.2 |
| $EROI_{\text{(total)}}$ | – | 0.30 |
| $EROI_{\text{(socialized)}}$ | – | 0.27 |
| CF_{food} | kg CO ₂ -eq per kg of food | 1.84 |
| CF_{protein} | kg CO ₂ -eq per kg of protein | 47.2 |

Table 5 Calculation and assessment of the nutritional quality (NRD 9.3 index) of the menus linked to their economic and environmental impact (cradle-to-school gate approach)

| Food per meal | | | | | | | |
|--------------------|----------|-------|-------------|---------|----------|----------------------------|-------------------------|
| Food groups | Food (g) | Kcal | Protein (g) | Fat (g) | CED (MJ) | CF (g CO ₂ -eq) | C_{food} (EUR) |
| Oil | 19.7 | 163.3 | 0.0 | 18.1 | 0.39 | 34.4 | 0.05 |
| Meat | 51.9 | 87.2 | 7.2 | 6.3 | 1.93 | 498.3 | 0.27 |
| Cereals | 49.8 | 157.2 | 4.5 | 0.6 | 0.57 | 59.4 | 0.07 |
| Fruits | 99.3 | 64.8 | 0.6 | 0.5 | 0.75 | 53.9 | 0.16 |
| Eggs | 23.8 | 34 | 2.7 | 2.5 | 0.75 | 97.6 | 0.05 |
| Dairy products | 23.4 | 24.1 | 1.4 | 1.5 | 0.86 | 56.5 | 0.04 |
| Legumes | 8.8 | 25.3 | 1.7 | 0.2 | 0.13 | 10.2 | 0.01 |
| Fish | 36.8 | 35.8 | 5.6 | 1.6 | 2.99 | 203.6 | 0.32 |
| Vegetables | 179.9 | 99.3 | 3.7 | 11.6 | 1.21 | 124.3 | 0.19 |
| Water and the rest | 214.2 | 12 | 0.2 | 0.3 | 0.56 | 27.8 | 0.04 |
| Total/average | 707.5 | 703 | 27.6 | 43.2 | 10.1 | 1,166.0 | 1.20 |

NRD 9.3 index (score): 278

efficiency, measured through $EROI_{\text{(socialized)}}$, was estimated at 0.27. In addition, CED_{food} and CED_{protein} were estimated at 15.13 and 392 MJ, respectively, per kilogram of food and protein served at the school canteens.

3.2 Calculation and assessment of the nutritional quality of the menus linked to their economic and environmental impact

Table 5 shows the nutritional composition of the average menu (amount of food, kilocalories, protein and fat) and its nutritional assessment according to the NRD 9.3 index as well as the CED, CF and monetary cost (cradle-to-school gate approach) for each of the main food groups served in the schools. Excluding bottled water, the meals provided to the students contain approximately 0.50 kg of food. This is slightly under 700 kcal, 27.6 g of protein and 43.0 g of fat per day, with a score of 278 on the NRD 9.3 index. A 30% reduction of salt consumption in the meals could advance the score to 381, a clear improvement. As shown in Figure 1, the total weight of food purchased (kg) was represented by vegetables (25.4%), fruits (14.0%), meat (7.3%) and fish (5.2%). From a nutritional viewpoint,

72.1% of the kilocalories supplied in the meals were accounted for by oil (23.2%), cereals (22.4%), vegetables (including potatoes) (14.1%), and meat (12.4%).

On the other hand, 61.1% of the proteins were concentrated in the consumption of animal products, especially fish (26.0%) and meat (20.3%), while cereals, vegetables and legumes accounted for 16.2%, 13.2% and 6.3%, respectively. Animal products represented 64.4% of the CED, 73.4% of the CF, and 57.0% of the cost of food for the school meals, thus revealing a positive correlation between the economic and the environmental cost of food. The monetary cost of vegetables (15.6%) and fruits (12.0%) is worth highlighting, although their environmental impact is relatively low: 10.7% and 4.6% of the CF, respectively. On the other hand, legumes only account for 1.2% of the cost, 1.3% of the CED and 0.9% of the CF.

3.3 Dietary change scenarios

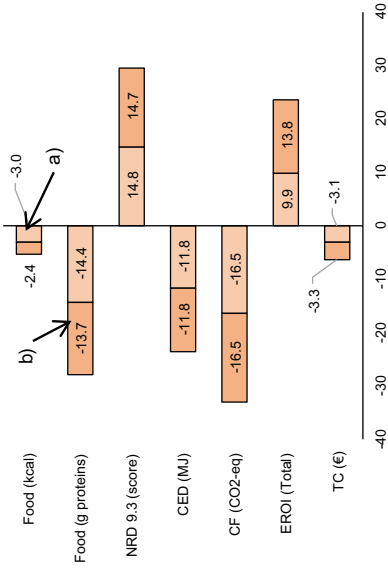
Figure 2 summarizes the reduction of the environmental impact and its economic and nutritional effects on the four scenarios proposed in this work relative to the baseline scenario (the average canteen diet). According to our model, the substitution of organic products for 30% or 60% of their conventional equivalents would allow for an 8.8% (S1a) or 16.4% (S1b) reduction of emissions as compared to the baseline scenario. In monetary terms, this change would lead to a 1.7% (S1a) and 3.1% (S1b) increase in the TC specifically connected to the purchase of food, but it would not modify the NRD 9.3 index score. Increasing the plant-based proportion of the diet by 30% or 60% would, in turn, allow for a larger reduction of the CF (by up to 33%) and a significant drop in the monetary cost (by up to 6.5%). Although reducing the consumption of animal products would result in a lower intake of proteins (by up to 28.1%), this dietary change would actually increase the NRD 9.3 index score. When the diet combines a decrease in the consumption of animal products and the introduction of organic foodstuffs, the reduction in the environmental impact is at its highest (emissions decrease by up to 45%) and that of the TC could be up to 2.3% in S3b. Finally, as shown in Figure 2, a 45% reduction in the consumption of animal products with a 60% substitution of organic products for conventional food would make it possible to reach a monetary balance (S4) and obtain important environmental and nutritional benefits.

4 Discussion

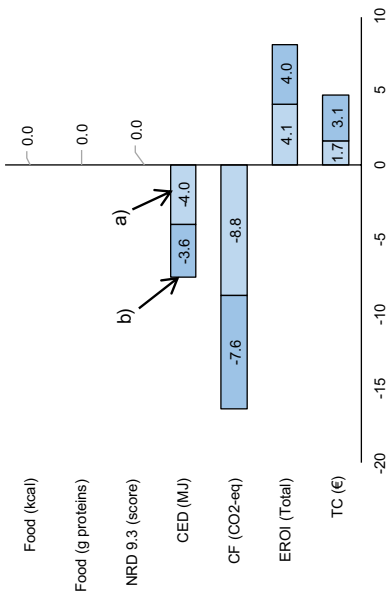
4.1 Environmental, nutritional and monetary impacts of school meals

The CF of the school canteens analyzed in this work is within the range of magnitude of previous studies (between 0.84 and 2.41 kg CO₂-eq per meal) (De Laurentiis et al. 2017; Cerutti et al. 2017; Tregear et al. 2019; Martínez et al. 2020). As menu weight is variable (between 0.36 and 0.61 kg per menu) (ib.), some authors have estimated the impact as a function of other functional units. For example, Tregear et al. (2019) estimate CF_{food} at between 1.55 and 4.89 kg CO₂-eq per kg of food for different European countries (1.84 in this work). Using “kilogram of food” as a functional unit allows for homogenizing weight differences in the menus. However, this functional unit also has limitations. Weight reports no nutritional food quality, so the intake of protein and other micronutrients required for maintaining an individual’s health and nutrition must be considered (Hossain et al. 2019).

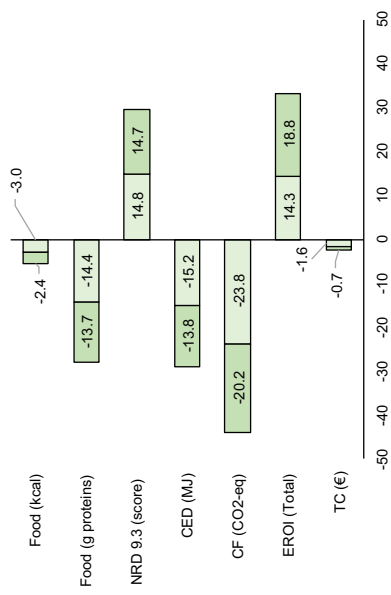
Scenario 2: a) 30% and b) 60% more vegetarian



Scenario 1: a) 30% and b) 60% more organic



Scenario 3: a) 30% and b) 60% more organic and vegetarian



Scenario 4: Monetary balance (±0.5%) (60-45% more organic-vegetarian)

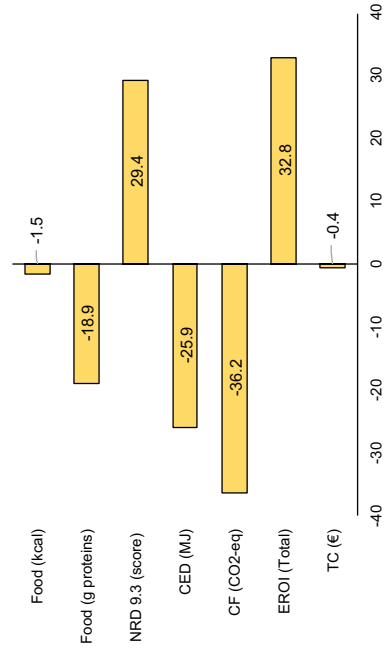


Fig. 2 Environmental impact reduction scenarios and their economic and nutritional effects in relation to the baseline scenario. CED, CF and EROI reflect impacts from cradle to grave, while the TC is calculated from a cradle-to-fork approach.

For example, products of animal origin have greater impacts than do those of plant origin when said impact is expressed in kilograms, but the difference decreases when the chosen functional unit is protein (Green et al. 2020). Studies using a nutritional LCA approach for linking environmental impact to protein intake in school canteens are scarce. Among them is the work of De Laurentiis et al. (2019) that estimates the CF at between 0.03 and 0.15 kg CO₂-eq per kg of protein for different menus in Italy (0.04 in this work). In this sense, more research is needed to assess the nutritional-health-environmental sustainability of school menus using other functional units.

The phase having the largest impact both in terms of energy and emissions is food production (also in Jungbluth et al. 2016; Martínez et al. 2020). More specifically, the production/consumption of meat and sea products is the main source of proteins, but it also contributes to the highest GHG emissions and makes highest energy demand. This relation between consumption of animal proteins and environmental impact is common to public school canteens (Saarinen et al. 2012; Caputo et al. 2014) and the generalized consumption pattern in Western societies (Westhoek et al. 2014; Poore and Nemecek, 2018). In particular, 60% of the CF of the average diet in Galicia is linked to animal products (Esteve-Llorrens et al. 2019). An excessive intake of veal is one of the main hotspots in the school canteens under analysis, followed by the consumption of other foodstuffs with high emission intensities, such as lamb, cheese, butter, pork or fish. These factors largely condition the environmental impact of school canteen diets and menus (see Batlle-Bayer et al. 2021). In terms of non-renewable energy use, the packaging and transportation phases are the most prominent given that an important percentage of the food is imported, and their supply requires long distance travel by land (Pérez-Neira et al. 2016; Benvenuti et al. 2016). This means that approximately 90% of the environmental impact of school meals is accumulated prior to the food even reaching Galician schools.

In monetary terms, the cost per meal (TC) is lower, for instance, than the one calculated by García-Herrero et al. (2019) for Italy (EUR 6.25). In contrast to the environmental impact, the cradle-to-school gate phases only accumulate 25.8% of the TC of the meal. The cost analysis shows how work associated with cooking and serving food is the main expenditure item (also in García-Herrero et al. 2019 and 2021). Moreover, in the case of Galicia, the gender pay gap is significant: women are the main employees in catering service companies; their salaries are usually lower than those of the more masculinized sectors (GHESTA, 2018; INE, 2021). These facts suggest that a strategy focusing on labor cost reduction may be unadvisable (García-Herrero et al. 2021). In nutritional terms, the score of the NRD 9.3 index in this work is slightly higher than the one obtained for the average Galician diet (242) (Esteve-Llorens et al. 2019), and lower than those calculated by Batlle-Bayer et al. (2021) for different low-impact school menus in the Spanish context (between 410 and 741). In this sense, it is important to underline that all low-impact diets are not necessarily healthy (Clark et al. 2018; Wickramasinghe et al. 2016 and 2017). For instance, plant-based diets with high nutritional quality indexes may lead to deficiencies in certain macronutrients, such as calcium, vitamin B12 or some long-chain fat acids (omega-3) (Castañé and Antón, 2017). Much planning, monitoring and optimization are therefore required for the provision and improvement of school meals (Ribal et al. 2016; Batlle-Bayer et al. 2021), and these tasks should include the implementation of processes to positively resolve the quadrilemma studied in this work (see also Abejón et al. 2020; Cambeses-Franco et al. 2021).

4.2 Measuring the environmental, nutritional and economic benefits of dietary change

The joint energy and carbon LCA, LCC and nutritional quality analysis allows us to observe how changes in the budget and management of school canteens (dietary change) may reduce the environmental impact of school meals without bringing down the nutritional quality of the food. The numerous environmental benefits of organic agriculture, especially that which is agroecologically produced (Smith et al. 2015; Meier et al. 2015), make it a production alternative that should be scaled up and spread (FAO 2018; Vara et al. 2021). The introduction of 60% of organic products in school menus while maintaining the same diet, would increase the cost of food procurement in our case study and, therefore, raise the TC of school meals by EUR 0.22 per person and day (4.8%). Even though the percentage is not high, it may not be viable in the presence of strict budget restrictions or pressure to achieve economic efficiency (Lehtinen, 2012; Smith et al. 2016). In the case of Italy, García-Herrero et al. (2019) obtain similar results: a 50% increase in organic food would raise the TC of the meal by 7%. As shown in scenarios 2b and 2c, replacing 30% or 60% of animal products with vegetable products (vegetables, legumes, fruits and cereals) leads to positive results in relation to the food quadrilemma: reducing the consumption of animal products, decreases GHG emissions and improves the nutritional quality of the menu, and leads to a significant drop in the TC of school canteen meals (and even results in improved efficiency in the case of other scenarios).

From an environmental point of view, the improvement is more pronounced when the change toward a more vegetarian diet is combined with the introduction of organic products (S3a and S3b). In this case, the reduction in the TC is less significant, but the nutritional quality of the food remains the same as in the more exclusively vegetarian scenario. Other studies provide evidence in the same direction (Castañé and Antón, 2017; Rockström et al. 2019; González-García et al. 2018; Fresán and Sabaté, 2019). In the case of school canteens, Cerutti et al. (2017) have shown how, in Italy, organic products and vegetarian diets reduce the CF by 11% and 42%, respectively, in relation to the baseline scenario. Thus, rethinking the diet and the management of school canteen menus provides the chance to introduce organic products and healthier meals in schools (Nuutila and Kurppa, 2017; Schreinemachers et al. 2018) by incorporating ovo-dairy vegetarian dishes along with fresh, seasonal products closer in proximity and replacing the most expensive ingredients with others that are cheaper and equally nutritive (Soares et al. 2017). These planned actions could provide organic foodstuffs of high nutritional value to all segments of the population regardless of their income level (Filippini et al. 2018). The results of our case study and the above-mentioned precedents in the literature should serve as a base to promote public policies supporting the practical implementation of win-win decisions through public food procurement to attain more sustainable models (IPES Food, 2019; Swenson and Tartanac, 2020).

4.3 Political implications: perspective, barriers and policies to foster more organic and vegetarian diets

The advancement of win-win food scenarios faces significant barriers at several levels (Shen et al. 2017; Neto and Gama Caldas 2018; Bonanno and Mendis, 2021) and different time periods (Chambers et al. 2020). Having more organic products in the menu

clashes with a lack of information on these products (Xie et al. 2015; Melovic et al. 2020) in addition to higher prices (Aschemann and Zielke, 2017; Filippini et al. 2018) and the fact that some consumers prioritize health benefits over environmental benefits (Jensen et al. 2011; Hjelmar, 2011). Multiple difficulties observed in the adoption of plant-based diets (see Biasini et al. 2021) are related to a lack of information on their health benefits (Lea et al. 2006) and other barriers difficult to isolate, such as the enjoyment of meat and other food habits (Pohjolainen et al. 2015). Several studies have shown how people's attitude toward vegetarian diets is linked to the frequency of consumption of animal products. When the consumption of these products is less frequent, we can observe that the consumers' attitude toward cooking and consuming plant-based meals, the protein content of such food and the availability of vegetarian foodstuffs, among other factors, is more positive (Hoek et al. 2011; Biasini et al. 2021). Barriers derived from the very nature of the products or from factors related to the consumers' inertia, such as "neophobia," i.e., the fear to adopt innovations of any kind, even food-related ones, are also mentioned in the literature (Hoek et al. 2011).

In this sense, public food procurement in schools can be a potent driver to overcome some of these rigidities (Strength2Food 2021) through the universalization of healthier more sustainable food habits among the youngest groups of age, as is already happening in different parts of the world (Kovacs et al. 2020; Wijesinha-Bettoni et al. 2021; Lopes et al. 2021), including Spain (Soares et al. 2017; Carrascosa-García et al. 2020). This work shows how adopting healthier low-carbon diets is inexpensive when public food procurement combines organic foodstuffs and plant-based menus. Yet the reduction in price does not necessarily increase the demand for such menus due to the weight of other factors shaping consumer attitudes (the aforementioned neophobia, lack of knowledge on the effects of vegetarian diets, etc.). The increase in the provision of organic products and local vegetables to public school canteens will therefore probably require the participation of regional producers and other actors (parents' associations, cooking staff, etc.) in the process of school food planning (Sonnino, 2009; Galli et al. 2014). This would contribute to the introduction of territorialized products distributed through more sustainable and responsive supply chains (Filho et al. 2019; Filippini et al. 2018). To this end, it will be necessary to implement synergic food policies, i.e., actions promoting an environmentally and socially responsible food governance model as one of the preferential political strategies (Carrascosa-García et al. 2020).

Hence, using food education to encourage the exchange of environmental and nutritional information about menus among students and families and integrating it into the school curriculum or developing specific didactic or dissemination materials can be a helpful tool to strengthen habits and commitments through both time (so that they last beyond the families' connection to the school) and space (inviting local groups such as neighborhood associations, older people's associations, etc. to participate) (De Laurentiis et al. 2017; Hyska et al. 2020; Moore et al. 2019). The consolidation of these habits will also require training in the operation of kitchens and the cooking of organic products and plant-based menus (Nuutila and Kurppa, 2017). Public food procurement based on environmental and nutritional criteria should be part of food transition plans that include specific actions involving the fields of education and healthcare as well as local producers and consumer organizations (Downs and Demmler, 2020). These plans may be designed at a higher territorial level than the one in which public procurement is decided, but they should always aim to enhance and strengthen synergies (Carrascosa et al. 2020). In some cases, changes in regulation in non-regional or local spheres may accelerate these transformative dynamics and contribute to scaling up alternative

food systems (IPES Food, 2019). All these mechanisms will facilitate the progress of win-win scenarios, promoting fairer and more far-reaching effects (Wiseman, 2008). Finally, the practical implementation of political measures affecting the configuration of the market, like subsidies or consumption taxes aimed at correcting the externalities of the economic processes, may also encourage the sustainable production of organic foodstuffs and support the shift toward healthier and more economically viable diets (De Laurentiis et al. 2017; Moberg et al. 2019).

4.4 Limitations and future lines of research

We would like to specify some limitations of this study that may open future lines of research. From an environmental perspective, it would be necessary to assess the menus using other categories to identify any hidden impacts or trade-offs from one phase to another (Mistretta et al. 2019). It would also be important to improve the information on organic waste to make a more accurate calculation of the energy efficiency (García-Herrero et al. 2019, 2021). Concerning the economic dimension, it is well known that market prices strongly determine the results, and these prices may fluctuate considerably among products and seasons throughout the year. In this sense, more longitudinal studies could allow for a further detailed comparative price analysis. From a nutritional perspective, the analysis should consider the differences between organic and conventional products as well as other complementary nutritional quality measures (Esteve-Llorens et al. 2021). In terms of sustainability policies, the effects of reducing packaging and transportation, increasing the consumption of local food, improving the energy efficiency of food preparation, or reducing organic waste should be explored (Poore and Nemecek, 2018; García-Herrero et al. 2019). The results could be tested through optimization models considering other economic (such as location of facilities, logistics, distribution, etc.) and environmental parameters (see Bojarski et al. 2009). In other words, the effectiveness of policy implementation throughout the whole agrifood system should be evaluated, as encouraged by agroecology (Gliessman, 2014; IPES Food, 2019). This opens up the field for new research to complete and make further advances in explaining the results obtained herewith.

5 Conclusions

This work shows how the food production phase and, particularly, the consumption of animal protein (meat and fish) are the main sources of energy consumption (CED) and GHG emissions (CF) in the school canteens under analysis. From an economic point of view, the labor involved in food preparation accounts for 65.4% of the TC. The current meal configuration can be substantially improved in environmental, economic and nutritional terms. Our analysis of the diet-environment-health-cost quadrilemma renders results demonstrating that introducing organic products reduces the environmental impact of school meals (up to 16.4% of the CF); yet it increases their price (up to 4.8% of the TC). This trade-off between environmental improvement and increased cost disappears when dietary changes also include the reduction of animal protein intake and their replacement by vegetable products. In this case, a higher consumption of vegetable products, in addition to increasing nutritional quality as measured by the NRD

9.3 index, may cut the cost by up to 6.4%. However, when more vegetarian and more organic menus are designed, the effect on the price is diluted and allows for an improvement in the four dimensions of the quadrilemma. In both situations, the reduction of energy consumption and GHG emissions could reach values between 4.4% and 29.0%; and 8.8% and 44%, respectively. These are undoubtedly very considerable and achievable results.

Introducing more vegetarian dishes would reduce the monetary and environmental cost of school meals, as well as enhance their nutritional quality according to the NRD 9.3 index. These two drivers of change—more vegetarian diets and more organic products—make it possible to achieve important positive environmental and nutritional effects without increasing monetary costs.

This work provides relevant information and substantive results that may help define public food policies in the regional context analyzed herein by establishing concrete, achievable and monitorable objectives (which implies the need for a further ongoing study of this topic). Of course, changes in this direction will require a greater commitment on the part of the competent public authorities as well as all the actors involved in the process in addition to new public policies to enable and encourage these innovations. Moving toward sustainable food models is far more than just a wish; it is also a political commitment at the European level as well as at the Galician level.

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