DESIGNING HEALTHY, CLIMATE FRIENDLY AND AFFORDABLE SCHOOL LUNCHES

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ABSTRACT

Purpose: This study aims to develop a model with which to build diets taking into account nutritional, climate change and economic aspects. A case study is used to test the proposed model, consisting of finding the optimal menus for school children in Spain from combinations of 20 starters, 20 main dishes and 7 desserts for a 20-day planning period.

Methods: An optimizing technique, specifically integer goal programming, is used as a means of designing diets which take into account the aforementioned aspects. Goal programming (GP) is used to design those menus that meet, or nearly meet, all the requirements with respect to caloric content, caloric share among macronutrients, nutrients to encourage and nutrients to limit, while reducing the carbon footprint (CFP) and the lunch budget. In order to have real, acceptable dishes, a school catering company provided information about the typical dishes they serve. The CFP of each dish was assessed, based on literature about life cycle assessment and CFP studies on food products. The nutritional value of each dish was obtained from databases, whereas prices were gathered from a wholesaler.

Results and discussion: After solving the goal programming model for several CFP and budget goals, the results show reductions with respect to the average CFP of between -13% and -24%, and reductions with respect to the average budget between -10% and -15% while maintaining the nutritional aspects similar to the average of the proposed menus. The results show that a wide range of budget is available, maintaining an almost constant CFP and meeting nutritional requirements to a similar degree; therefore, it is possible to avoid trade-offs between the CFP and the budget. The analysis of the dishes selected shows how the optimization model, in general, avoids the dishes which have a high CFP and high price and which are low in iron content, but high in protein and cholesterol.

Conclusions: Goal programming constitutes a suitable tool for designing diets which are economically, environmentally and nutritionally sustainable. Its flexibility enables specific issues to be studied, such as the existence of possible trade-offs between budget and CFP, attained by changing the budget and the CFP goals. By means of an iterative process, new dishes could be introduced or the existing ones could be improved, thus providing catering companies with useful information.

Keywords: Carbon footprint, goal programming, sustainable diets, school lunch.

1. INTRODUCTION

It is well known fact that by improving how students are fed they will enjoy better health and a greater sense of wellbeing, contributing to a reduced risk of chronic diseases in adulthood (Martínez Álvarez et al. 2012). This is of special importance in Spain, considering the data on the prevalence of childhood obesity (19.1%) and excess weight (26.1%), as shown in the Aladino study (AESAN 2011). Furthermore, as a consequence of the economic recession, other reports show that in the last few years a growing number of children have been suffering from malnutrition and school lunch is their most important meal of the day (UNICEF España 2014). On the other hand, we should not forget that the food sector contributes 15-30% of the total greenhouse gas emissions and, as such, food choices can have a notable influence on the environment, specifically on climate change. And at the same time, as Lang (2005) states, *the environment is nutrition's invisible infrastructure, everywhere but nowhere*, since the environment is fundamental when obtaining food but, when nutritional recommendations are made, no one pays attention to it. Nevertheless, price is the most decisive factor when choosing food (Vanclay et al. 2011), in this case for both the students' parents and school catering companies. These three aspects, health, climate change and cost, need to be borne in mind in order to build sustainable lunches.

The FAO definition of a sustainable diet reads "*those diets with low environmental impacts which contribute to food and nutrition security and to a healthy life for present and future generations. Sustainable diets are protective and respectful of biodiversity and ecosystems, culturally acceptable, accessible, economically fair and affordable; nutritionally adequate, safe and healthy; while optimizing natural and human resources*" (FAO 2010). However, these aspects are not necessarily convergent, as recent studies have shown (Vieux et al., 2013; Thibert and Badami 2011), which makes the design of sustainable diets a complex task. On the one hand, dietary guidelines have been developed to facilitate the attainment of nutrient recommendations, although their effectiveness remains questionable because of socioeconomic factors and food preferences (Maillot at al. 2010). On the other hand, the complexity of the food chain must be taken into account when selecting the foods, since the same food can have different origins, can be grown in different ways (e.g. organic or conventional agriculture) and different processing techniques can be used (e.g. concentrated juice vs. pasteurized one). In the last few years, this issue of sustainability has been tackled by using mathematical modelling, specifically linear programming, to design or modify environmentally friendly diets so that they provide the recommended levels of relevant nutrients (e.g. Macdiarmid et al. 2012; Tyszler et al. 2014; van Dooren and Aiking 2014).

In this context, this study aims to develop a model with which to build diets, taking into account nutritional, climate change (as an aspect of environmental sustainability that is discussed later on in this introduction) and economic aspects. An optimizing technique, specifically Integer

Goal Programming (GP) is used as a means of designing diets which include all these aspects. GP is an extension of linear programming that permits more than one objective to be stated. Integer goal programming models are of particular use when formulating many practical problems that have both logical conditions and multiple, conflicting goals (Jones and Tamiz, 2010).

Although climate change, measured through the carbon footprint (CFP), represents only one part of the environmental impacts of food products, the relationship between food consumption patterns and climate change is a subject of great concern (Carlsson-Kanyama and González 2009). In spite of the limitations of assessing only one impact, CFP presents several advantages that have made it a commonly-used indicator for the eco-labelling of food products. A major advantage is its reduced complexity when computing and interpreting the results (Weidema et al. 2008; Heller et al. 2013), which is related to the global character of climate change. Other impact categories, such as land use, water use and toxicity, also relevant in food life cycles, are associated with regional impacts, making data sets less applicable depending on the region and adding uncertainty to the calculations.

A case study is used to test the proposed model, consisting of finding the optimal menus for school children from combinations of pre-designed starters, main dishes and desserts. GP is used to select those dishes from the pre-set group in order to design a 20-day menu trying to attain the requirements determined by the planner (global warming, nutritional and economic aspects) in the best possible way. In the context of decision making, to optimize means to find the decision which gives the best possible value of some measures from amongst the set of possible decisions (Jones and Tamiz 2010). By establishing two goals, an economic one and a CFP one, positive deviations can be minimized while keeping the recommended daily intake (RDI) fractions (macronutrients and micronutrients) and energy content in the expected range or near it.

2. METHODS

To make decisions which take into account several, non-convergent criteria implies the application of a weighting method, namely Multicriteria Decision Making Methods (MCDM). There is a wide range of MCDM, but in order to design sustainable menus we do need a flexible method that enables different kinds of goals to be integrated; i.e. to minimize cost and CFP levels, to ensure that the energy content is between a minimum and maximum and also to guarantee that the kilocalories shared out among the macronutrients are set in the right intervals. Simultaneously, some micronutrients should be encouraged (vitamins, calcium, iron, magnesium…) while others should be limited (sodium, cholesterol…) (Drewnowski 2009). Moreover, the importance of each criterion can be different: e.g. we want to be sure that the caloric content share of macronutrients is above a certain amount on a monthly basis (strong condition), but at the same time we would like the CFP to be around a certain level or goal. The latter means that the CFP could be higher than the required goal, although the solution is sought by trying to minimize any positive deviation above the CFP, which is a so-called "weak condition". GP allows all these conditions to be addressed when designing diets.

2.1. Case study

A case study is used to test the proposed model. It must be considered that the aim of the study is to design a lunch for an elementary school student for a month, that is, 20 school days. For that purpose, and in order to have real, acceptable dishes, a school catering company provided information about the typical dishes they serve. From this information, together with the availability of published CFP data, the dishes for the case study were chosen and slightly modified in some cases. Since a well-designed diet must promote, among other criteria, variety (MSC 2008) 20 starters, 20 main courses and 7 desserts were used as a starting point (see Table 1 in the supporting information). From these dishes, combinations were made to obtain up to 2,800 lunch menus. The reason to use 20 starters is because a school month has on average 20 days, although only 7 desserts were used taking into account that they are repeated more often. Following the recommendations of the Spanish Guide for School Canteens (MSC 2008), lunches were designed to be served with bread and water, as the only drink, which is usual for children in Spanish schools.

2.2. Carbon footprint of the menus

The CFP of each dish was assessed, based on literature dealing with life cycle assessment and CFP studies into food products (see Table 2 in the supporting information). Although all the functional units of data-providing studies were based on mass or volume, the use of literature data demanded the results of numerous studies be adapted to the chosen functional unit for each food product, which is 1 kg of product, prepared and ready to eat, in a Spanish school. To calculate the CFP of the daily menus, the preliminary results per kg of food product were multiplied by menu composition (Table 1 in the supporting information). Several standards have been proposed for the purposes of calculating the CFP, among them Product GHG Protocol (2011) and ISO 14067 (2014), which benefits from being an international structure. Nevertheless, according to an assessment carried out for the EU (Ernst and Young 2010), the British PAS 2050:2011 (BSI 2011) specification was identified as the most mature and complete standard for calculating the CFP. For this reason, the PAS 2050:2011 guidelines (BSI 2011) were used to analyse all CFP data sources in terms of their system boundaries, completeness and appropriateness (key words from PAS 2050 are printed in italics). The *production of materials* was included in all the literature studies, except for packaging materials. Where no data was available, the impact of packaging was assumed to be negligible (Jungbluth et al. 2000). This is especially true for plastic and cardboard (see for instance Tobler et al. 2011), the packaging materials for frozen products, which are the ones most commonly used in catering companies and also in this case study. Of the products proposed, tuna and tomato sauce are the only products that are canned, but in these cases the packaging was already included in the CFP data sources. The *energy* provision was included in all the studies reviewed. The *manufacturing* and *service provision* were either included in the literature sources or added manually. Since some literature sources consider only primary food production, when energy consumption from the processing step is missing, adaptations were made using literature data or models. For instance, since catering companies mostly use frozen products, energy for freezing was calculated following Sanjuan et al. (2014) and then from the corresponding electricity grid mix from Ecoinvent v 2.0 the CO_2eq. *Capital goods* were excluded, as recommended by PAS 2050:2011 (BSI, 2011). The *transport* processes were either included in the literature sources or added manually, taking into account both the distance from the food origin to the consumption point (Valencia, Spain) and also the means of transport from Ecoinvent v 2.0. Cooling during transportation was added if not previously included. The same procedure applied to the *use phase* in the kitchen, which was either part of the literature source or was included by using data from the LCA Food Database (Nielsen et al., 2003), Carlsson-Kanyama and Faist (2000) and Foster (2006). The *storage* of the food products in the catering kitchen was calculated according to Sanjuan et al. (2014), taking 15 days as the storage time.

The origin of the products was chosen according to literature data availability and to Spanish statistics on food imports (FEPEX 2014; MAGRAMA 2013). The modular method for the extrapolation of crop LCA (MEXALCA; Roches et al. 2010) was applied in order to reach a geographical specificity when literature from other countries was used. Details about the life cycle stages added to each product, the origin, and the applied regionalization can be found in the supporting information, together with Table 2 in the same supporting information. Table 1 shows the CFP of each dish.

2.3. Cost of the menus

The cost was calculated from the market prices of the raw foods. The source for food prices was one of the most important wholesalers in Spain. Only the price of raw materials has been taken into account; neither labour costs nor other direct costs have been computed. Table 1 shows the price of each dish.

Labour costs can represent a significant proportion of the cost incurred by a school catering company. For an average school, companies usually employ a cook and two assistants whatever the school menu for the day, consequently, labour costs of labour can be considered a fixed cost. This fixed cost could be distributed through the total number of menus to be served. In order to avoid stating the dimension of the school canteen or the number of students, this cost has been left out. Since it is a fixed cost, it would not change the solution of the GP model.

2.4. Nutritional value of the menus

To assess the nutritional value of the dishes, the caloric content together with the macronutrients (protein, fat and carbohydrate) and some key micronutrients of each food were obtained from the Spanish GEA database (BEDCA 2014). The nutritional values of each dish are shown in Table 1. Fibre, calcium, iron, potassium, magnesium, vitamin A, vitamin C, vitamin E were considered as micronutrients to be encouraged, while saturated fatty acids, cholesterol and sodium were considered as three nutrients to be limited. Table 2 shows the bounds (threshold values) used as a minimum, a maximum or as an interval.

The threshold values of nutrients to be used as constraints in the programming were fixed as 30% of the reference daily values obtained from the Spanish literature (Moreiras et al. 2011). Although the number of meals that children have during the day depends on the family habits, the recommendations from the Spanish Guide for School Canteens (MSC 2008) are to have between 4-5 meals per day and to consume most of the foods in the first part of the day, that is, to have a good breakfast (20-25% of the daily caloric content) and lunch (30-35% of the daily caloric content).

2.5. Goal programming model

Each goal programming needs an objective function to be optimized, which usually consists of minimizing the unwanted deviations of some goals. In our case study, these deviational variables come from the nutrient content, CFP and budget constraints. Negative deviations are set from the nutrients to be encouraged and positive deviations from those to be limited. Caloric content makes up interval goals (lower bound-upper bound) and, therefore, negative deviations have to be minimized from the lower bound and positive deviations from the upper one. Fig. 1 shows the types of goals as well as the unwanted deviations for each goal.

The objective function is made up of four main addends; the first one includes positive deviations from the CFP goal, whereas the second one includes positive deviations from the budget goal. The third addend refers to the daily negative deviations from the lower bound of caloric content (600 kcal) and the daily positive deviations from the upper bound of caloric content (800 kcal). Other nutrients to be encouraged and limited build the fourth addend, specifically negative deviations from the lower bound of the nutrients to be encouraged and positive deviations from the upper bound of the nutrients to be limited.

A weight (w_i) of 25% has been applied to each addend that represents the relative importance of the addend to the decision maker. There can be several ways to fix weights in a decision-making process. In this specific case study, an equal weight approach has been opted for. Nevertheless, some tests using a *nutrition first* approach obtained similar results. The *nutrition first* approach was defined by setting a 90% weight for nutritional goals and a 10% weight for CFP and budget goals.

At the same time, each deviational variable has been divided by a normalization factor that scales the deviations so they can be compared in the same units. The normalization factor is taken from the bound of the respective aspect (CFP, budget, kcal, nutrients…). The third addend has also been divided by 20 so as to obtain the average daily deviation. In the same way, the fourth addend has been divided by 20 and by the number of nutrients to encourage and to limit, which is 10.

Macronutrient content has not been introduced into the objective function, but fixed as a strong constraint for the planning period. The main reason is that macronutrient content is a percentage of the caloric content. Therefore, the caloric content is not constant as it changes according to the dish chosen. Since this is linear programming, we cannot divide the macronutrient content (e.g. fat caloric content) by the total caloric content because both are determined by the chosen dishes. This issue can be overcome by linearizing the constraint. However, the goals of the objective function need, as explained before, to be normalized and in this case the linearization change cannot be used. As a result, neither macronutrients nor saturated fatty acids are included in the objective function, but only in the constraints. This way, the macronutrient caloric content recommendations must be followed for the planning period.

The decision variables are: (20 starters +20 main dishes + 7 desserts) x 20 days = 940 variables

Xs_{ij}: variable of starter j on day i

Xs_{ij}: variable of main dish j on day i

Xd_{ij}: variables of dessert j on day i

All of these are binary variables; they can only take the values 0 or 1. For example, if $Xs_{ij}=1$, it means that starter *j* is part of the lunch on day *i*, otherwise starter *j* is not part of the lunch on day *i*.

There are 6 groups of constraints in the goal programming:

- Budget constraint: 1 constraint for the whole planning period
- CFP constraint: 1 constraint for the whole planning period
- Caloric content constraints: (20 days x 2 levels [lower and upper]) = 40 constraints
- Macronutrient constraints: (2 levels x 3 macronutrients) = 6 constraints for the whole planning period
- Nutrients-to-encourage constraints: (20 days x 8 nutrients) = 160 constraints
- Nutrients-to-limit constraints: (20 days x 2 nutrients) = 40 constraints
- Saturated fatty acids constraint = 1 constraint for the whole period

The goals of these constraints are termed RHS (Right Hand Side of each equation). There are also some other constraints related to the composition of the menus: the starters and the main dishes cannot be repeated more than twice in the planning period and the desserts cannot be repeated more than six times. Since weights are included in the objective function and some constraints are defined as intervals, the model to be built is a mixture between weighted goal programming and interval goal programming.

In the same way as cholesterol or sodium, saturated fatty acids have to be limited; however, the structure of the constraint is different since the limit is a percentage (10%) of the caloric content. In fact, the structure of the constraint is similar to Eq 6 to Eq 11.

Bearing all these features in mind, the goal programming can be written this way, *i* being: the number of the day (1 to 20); *j*: the number of the dish (1 to 20 for starters and main dishes, 1 to 7 for desserts); and *k*: the number of the nutrient (1 to 8 for nutrients to be encouraged and 1 to 2 for nutrients to be limited).

$$MIN\left[p_{budget} / RHS_{budget}\right] \cdot w_1 + \left[p_{CFP} / RHS_{CFP}\right] \cdot w_2 + \left[\sum_{i}^{20}\left(n\_cal_i^L / RHS_{cal}^U + p\_cal_i^U / RHS_{cal}^U\right)/20\right] \cdot w_3 +$$

$$+\left[\sum_{i}^{20}\begin{pmatrix} n\_water_i + n\_fiber_i + n\_calcium_i + n\_iron_i + n\_pota_i + n\_magne_i + n\_vitA_i + \\ + n\_vitC_i + n\_vitE_i + p\_cholest_i + p\_sodium_i \end{pmatrix}/(10 \cdot 20)\right] \cdot w_4 [Eq.1]$$

s.t.

Budget constraint :

$$\sum_{i}^{20}\left[\sum_{j}^{20} Xs_{ij} \cdot price\_s_j + Xm \cdot price\_m_j + \sum_{j}^{7} Xd_{ij} \cdot price\_d_j\right] - p_{budget} + n_{budget} = RHS_{budget} [Eq.2]$$

CFP constraint :

$$\sum_{i}^{20}\left[\sum_{j}^{20} Xs_{ij} \cdot CFP\_s_j + Xm \cdot CFP\_m_j + \sum_{j}^{74} Xd_{ij} \cdot CFP\_d_j\right] - p_{CFP} + n_{CFP} = RHS_{CFP} [Eq.3]$$

Caloric content constraints :

$$\sum_{j}^{20}\left(Xs_{ij} \cdot cal\_s_j + Xm_{ij} \cdot cal\_m_j\right) + \sum_{j}^{7} Xd_{ij} \cdot cal\_d_j - p_{cal\_i}^L + n_{cal\_i}^L = 600 \qquad \forall i = 1..20 days [Eq.4]$$

$$\sum_{j}^{20}\left(Xs_{ij} \cdot cal\_s_j + Xm_{ij} \cdot cal\_m_j\right) + \sum_{j}^{7} Xd_{ij} \cdot cal\_d_j - p_{cal\_i}^U + n_{cal\_i}^U = 800 \qquad \forall i = 1..20 days [Eq.5]$$

Macronutrient constraints :

$$\sum_{i}^{20}\left(\sum_{j}^{20}\left(Xs_{ij} \cdot prot\_s_j + Xm_{ij} \cdot prot\_m_j\right) + \sum_{j}^{7} Xd_{ij} \cdot prot\_d_j\right) - \left[\sum_{i}^{20}\left(\sum_{j}^{20}\left(Xs_{ij} \cdot cal\_s_j + Xm_{ij} \cdot cal\_m_j\right) + \sum_{j}^{7} Xd_{ij} \cdot cal\_d_j\right)\right] \cdot 0.12 \geq 0 [Eq.6]$$

$$\sum_{i}^{20}\left(\sum_{j}^{20}\left(Xs_{ij} \cdot prot\_s_j + Xm_{ij} \cdot prot\_m_j\right) + \sum_{j}^{7} Xd_{ij} \cdot prot\_d_j\right) - \left[\sum_{i}^{20}\left(\sum_{j}^{20}\left(Xs_{ij} \cdot cal\_s_j + Xm_{ij} \cdot cal\_m_j\right) + \sum_{j}^{7} Xd_{ij} \cdot cal\_d_j\right)\right] \cdot 0.15 \leq 0 [Eq.7]$$

$$\sum_{i}^{20}\left(\sum_{j}^{20}\left(Xs_{ij} \cdot fat\_s_j + Xm_{ij} \cdot fat\_m_j\right) + \sum_{j}^{7} Xd_{ij} \cdot fat\_d_j\right) - \left[\sum_{i}^{20}\left(\sum_{j}^{20}\left(Xs_{ij} \cdot cal\_s_j + Xm_{ij} \cdot cal\_m_j\right) + \sum_{j}^{7} Xd_{ij} \cdot cal\_d_j\right)\right] \cdot 0.30 \geq 0 [Eq.8]$$

$$\sum_{i}^{20}\left(\sum_{j}^{20}\left(Xs_{ij} \cdot fat\_s_j + Xm_{ij} \cdot fat\_m_j\right) + \sum_{j}^{7} Xd_{ij} \cdot fat\_d_j\right) - \left[\sum_{i}^{20}\left(\sum_{j}^{20}\left(Xs_{ij} \cdot cal\_s_j + Xm_{ij} \cdot cal\_m_j\right) + \sum_{j}^{7} Xd_{ij} \cdot cal\_d_j\right)\right] \cdot 0.35 \leq 0 [Eq.9]$$

$$\sum_{i}^{20}\left(\sum_{j}^{20}\left(Xs_{ij} \cdot CH\_s_j + Xm_{ij} \cdot CH\_m_j\right) + \sum_{j}^{7} Xd_{ij} \cdot CH\_d_j\right) - \left[\sum_{i}^{20}\left(\sum_{j}^{20}\left(Xs_{ij} \cdot cal\_s_j + Xm_{ij} \cdot cal\_m_j\right) + \sum_{j}^{7} Xd_{ij} \cdot cal\_d_j\right)\right] \cdot 0.50 \geq 0 [Eq.10]$$

$$\sum_{i}^{20}\left(\sum_{j}^{20}\left(Xs_{ij} \cdot CH\_s_j + Xm_{ij} \cdot CH\_m_j\right) + \sum_{j}^{7} Xd_{ij} \cdot CH\_d_j\right) - \left[\sum_{i}^{20}\left(\sum_{j}^{20}\left(Xs_{ij} \cdot cal\_s_j + Xm_{ij} \cdot cal\_m_j\right) + \sum_{j}^{7} Xd_{ij} \cdot cal\_d_j\right)\right] \cdot 0.55 \leq 0 [Eq.11]$$

Nutrients - to - encourage constraints :

$$\sum_{j}^{20}\left(Xs_{ij}\cdot encou_{k}\_s_{j}+Xm_{ij}\cdot encou_{k}\_m_{j}\right)+\sum_{j}^{7}Xd_{ij}\cdot encou_{k}\_d_{j}-p_{CH\_i}^{U}+n_{CH\_i}^{U}=RHS_{encour\_i}\qquad \forall i=1..20days[Eq.12]$$

$\forall k = fiber, calcium, iron, potasium, magnessium, vitA, vitC, vitE$

Nutrients - to - limit constraints :

$$\sum_{j}^{20}\left(Xs_{ij}\cdot \lim it_{k}\_s_{j}+Xm_{ij}\cdot \lim it_{k}\_m_{j}\right)+\sum_{j}^{7}Xd_{ij}\cdot \lim it_{k}\_d_{j}-p_{CH\_i}^{U}+n_{CH\_i}^{U}=RHS_{\lim it\_i}\qquad \forall i=1..20days[Eq.13]$$

$\forall k = cholesterol, sodium$

Saturated fatty acids constraint

$$\sum_{i}^{20}\left(\sum_{j}^{20}\left(Xs_{ij}\cdot sfa\_s_{j}+Xm_{ij}\cdot sfa\_m_{j}\right)+\sum_{j}^{7}Xd_{ij}\cdot sfa\_d_{j}\right)-\left[\sum_{i}^{20}\left(\sum_{j}^{20}\left(Xs_{ij}\cdot cal\_s_{j}+Xm_{ij}\cdot cal\_m_{j}\right)+\sum_{j}^{7}Xd_{ij}\cdot cal\_d_{j}\right)\right]\cdot 0.10\le 0[Eq.14]$$

Decision variable constraints :

$$\sum_{i}^{20}\mathrm{Xs}_{\mathrm{ij}}\le 2\qquad \forall j=1..20\ \text{starters}[Eq.15]$$

$$\sum_{i}^{20}\mathrm{Xm}_{\mathrm{ij}}\le 2\qquad \forall j=1..20\ \text{main dishes}[Eq.16]$$

$$\sum_{i}^{20}\mathrm{Xd}_{\mathrm{ij}}\le 6\qquad \forall j=1..7\ \text{desserts}[Eq.17]$$

$$\sum_{i}^{20}\sum_{j}^{20}Xs_{ij}\ge 20\qquad \sum_{i}^{20}\sum_{j}^{20}Xm_{ij}\ge 20\qquad \sum_{i}^{20}\sum_{j}^{20}Xd_{ij}\ge 20\qquad [Eq.18]$$

The GP model has been written in Lingo modelling language and solved by means of the LINGO 6.0 software. Using binary variables implies an integer linear programming whose solver algorithms are not as efficient as the simplex algorithm used in linear programming. This means that more time is needed for the solving; nevertheless, by adjusting some of the parameters of the solver algorithms and solving by first taking only a part of the decision variables as integer and keeping them as a starting point for a second solving the process can be speeded up dramatically.

While the nutritional goals for the GP model are externally fixed from Spanish nutritional guidelines, the goals for the budget and the CFP need to be set and thus can be changed. In fact they have been changed, in order to analyse possible trade-offs in the solution of the model. To define these goals, the 20^{th} to 90^{th} percentile values of the CFP and the budget of the 2,800 combination menus have been calculated.

3. RESULTS

3.1. Solutions of the GP model

It must be kept in mind that the GP model selects the dishes that make up each lunch menu for a 20-day period, which minimizes the objective function. For this reason, and for the purposes of comparing the results of the GP with the average menu and the 2,800 initial menus, Fig. 2 has been built. Considering the 2,800 initial menus and extending each menu over the 20-day period, the CFP for 20 days and the 20-day budget for each menu have been calculated (each single menu x 20) and plotted in red. Therefore, the cloud of red dots is made by assuming that each possible menu (a combination of one starter, one main dish and one dessert) was repeated for 20 days; this is, of course, an unrealistic assumption (a child does not eat the same lunch every day) but it provides a graphical comparison framework with which to plot the solutions (budget-CFP pairs) of several runs of the goal programming for the planning period. The CFP and budget of the average menu (average of the 2,800 combinations) has also been plotted in black.

A first group of solutions has been obtained by combining CFP goals as percentiles from the 20th to 90th with budget percentiles from the 20th to 90th. In this way, reductions in the CFP and the budget can be tested. This group of solutions has been termed *equal weights*, since $w_1=w_2=w_3=w_4$ and they are also plotted in Fig. 2 as white dots. The different solutions are roughly distributed in a curved line. This line shows that the budget is quite constant for different CFP percentile goals (vertical part of the curve). At the same time, when changing the budget percentile goals the CFP is also quite constant (horizontal part of the curve). With respect to the average CFP, the reductions are around 23-24% in the horizontal part of the curve, whereas compared with the average budget the reductions are around 15-16%. For example, fixing both goals in the 40th percentile leads to a 23.6% reduction in the average CFP and a 15.3% reduction in the average budget. In nutritional terms, if the average menu is compared with the solutions on the curve, the latter shows a lower calcium content for the planning period (below the set threshold), while the energy share among the macronutrients is much more balanced than that of the average menu. The results also show a vitamin E deficit which is similar to the deficit in the average menu.

The GP can be tweaked in order to analyse specific questions. The influence of the budget on the CFP can be tested by taking economic and CFP deviations out of the objective function and forcing the budget to be below specific values: 20th budget percentile, 30th budget percentile,... This way, the GP model has been solved for each budget percentile and a second group of solutions has been obtained. This group of solutions has been termed *free CFP* and it is plotted in blue in Fig. 3. In the same way, the influence of the CFP on the budget can be calculated and is shown as black dots in Fig. 3. The blue dots show the evolution of the CFP according to the limitations in the lunch budget as an almost horizontal line, around 31 kg-eq CO_2; as can be observed, a small budget does not lead to a higher CFP. From the nutritional point of view, lower budgets exhibit a similar level of deviation from the nutritional goals to the higher budgets. The black dots show the evolution of the budget according to the limitations in the CFP as an almost vertical line, around 24 €.

Table 3 shows the energy content and the energy share among nutrients for the average menu and also for some combinations of CFP and budget goals. The energy content distribution is beyond the recommended interval for the average menu. Specifically, it is low in carbohydrates and high in protein, whereas it is within the recommended interval for the solutions of the GP, as it was forced in some of the constraints [Eq. 6 to Eq. 11]. As regards the nutrients to encourage (Table 4), the average menu meets the reference values except in the case of vitamin E, as commented on above. The saturated fatty acids content is slightly beyond the recommended bound (10%) in the average menu, but it is below 10% in the solutions of the model as forced in constraint Eq.14. Different solutions of the GP model can improve the macronutritional content and meet the micronutrient requirements, except in the case of calcium, while reducing the CFP and the budget.

3.2. Dishes selected by the GP model

Table 5 shows the number of times that a specific dish (starter, S, main dish, M, and dessert, D) is selected by the GP model, termed as 'equal weights', for several CFP and budget percentile goals. The solutions of the GP model for each day show that some starters and main dishes are not part of the solution, while other dishes appear twice in the planning period. As explained in section 2.5, the desserts cannot be repeated more than six times. It must be pointed out that, when characterizing the most commonly selected dishes, it is difficult to define the features they have in common, since there are many parameters involved in the GP model. For instance, we can find a dish, like the grilled chicken with baked potatoes (M20), which has the highest potassium content of the main dishes (a nutrient to be encouraged), but also the highest cholesterol content (which should be limited), as can be observed in Table 1.

As for the starters, the ones that have not been selected are peas with ham (S01), green salad with lentils (S02), lentils with potatoes (S04) and three-cheese macaroni (S05). S01 and S05 present a high CFP; S02 and S05 present a high protein and calcium content together with the highest saturated fatty acid content. The selection of these dishes would help to raise the calcium content, but at the same time it would worsen the protein and saturated fatty acid content. Therefore, the GP model tries to avoid those dishes with a high protein and saturated fatty acid content.

The most commonly selected starters are rice salad with apple (S03), pasta salad (S08), sautéed green beans (S11), rice with tuna and onions (S13) and pasta with onion (S20). S13 has a low CFP, S11 presents low protein and high vitamin E contents, and S03 has a high carbohydrate content. Starters S03 and S11 are the ones with the lowest cholesterol, S03 also presenting the lowest sodium content, while S20 is low in price.

The most commonly selected main dishes are trout with tomato sauce and rice (M06), chicken à l'orange (M09), cod Vizcaya style (M13), grilled chicken with peas (M14), trout with sauce (M15), fried angler fish (M16) and grilled beef steak (M17). All of these are low in protein and have a low CFP, except for M16 and M17 whose CFP is high. Another common feature among these dishes is that they are all low in cholesterol and high in iron, except M17. Furthermore, M14 and M09 are among the ones with the lowest budget. While M16 and M06 have the highest vitamin E content of the list, the rest also present a relatively high content in this vitamin, except M14.

On the other hand, roast chicken with vegetables (M04), megrim Meunière (M05), battered megrim (M10), tuna in papillote (M11), pork with green beans (M19) and grilled chicken with potatoes (M20) have not been selected at all. They all have a high CFP, especially M04, M05, and M20, and dishes M05 and M11 are also expensive. As far as the nutritional value is concerned, they all present high protein content, except M05. All of them are low in iron and vitamin E content; in fact, M05 and M20 have the lowest vitamin E content. As regards the nutrients to be limited, it must be pointed out that the cholesterol content of the non-selected main dishes is high; specifically, M04 and M20 present the highest content.

As to the desserts, it can be observed that ice cream (D03) is the most commonly selected one, followed by banana (D04) and apple (D05). Although the ice cream has a high CFP and price, it is high in calcium and vitamin E content, which, of the micronutrients present in the proposed dishes are the two with the lowest content. Kiwi (D07) is only selected once in the 20-day menu and plain yoghurt (D01) is not selected; raspberry yoghurt (D06), on the other hand, is selected 5 times since its CFP is slightly lower than that of plain yoghurt.

4. DISCUSSION

The results show how it is possible to obtain menus for a planning period from a selected group of dishes which are more affordable and more climate-friendly than the average of the group of proposed menus while keeping nutritional values at a similar or even higher level. The analysis of the selected dishes shows how the optimization model, in general, avoids the dishes with a significant CFP, a high price and that are low in iron and high in protein and cholesterol.

Some nutritional aspects have been modelled as aspirational goals in the specific models used in the case study, which allow that the goal is not entirely achieved. The calcium deficit is explained by the fact that the constraints force the energy contents among the macronutrients [Eq.6 to Eq.11]; this is because it is a strong constraint (the GP model forces the share of the energy contents to be within the limits) while the calcium constraint is a weak one (the program tries to minimize the negative deviation). There is a positive correlation between the protein and calcium contents in the group of available dishes. Inasmuch as the protein content of the average menu is greater than the upper limit, the solutions of the model reduce the number of dishes rich in protein and, hence, they also reduce the overall calcium content. Nevertheless, it must be pointed out that this is a lunch design and the biggest part of the calcium intake takes place by consuming dairy products for breakfast or dinner.

The calcium issue illustrates the flexibility of GP; the calcium deficiency could be overcome by partially rewriting the model to force all the nutritional requirements to be completely fulfilled. A different structure of constraints might be used, e.g. weak constraints on a daily basis but strong constraints on a weekly/monthly basis, in this way the positive deviations of the nutrients-to-encourage goal could be minimized on a daily basis while forcing a minimum to be reached for the planning period. In order to test this, new constraints forcing the micronutrients-to-encourage to be over the threshold for the whole period were introduced into the model. No solution that simultaneously accomplished the recommendations of both macronutrient caloric share and calcium content was found. To increase the calcium content, new ingredients might be introduced into the set of available foods, e.g. by adding vegetable sources of calcium not linked to high protein content. However, any change implies that consumers, and specifically children, would have to make an effort to adopt dietary changes; for this reason, Maillot et al (2010) and Tyszler et al (2014) penalize the introduction of new foods in their linear programming models, and Tyszler et al (2014) also change the portion of foods depending on their popularity. In our study, the model has been designed for the purposes of choosing dishes, hence, the decision variables are integer (0/1), but these decision variables could also be defined as the quantity of each dish and this would lead to better solutions.

The results also show some interesting aspects related to the CFP and the cost of food. Specifically, a wide range of budgets is available, keeping an almost constant CFP and meeting nutritional requirements in a similar way; therefore, it is possible to avoid trade-offs between the CFP and the food budget. This fact has been proved by changing the CFP and budget goals (equal weights model) and also by taking the CFP goals and budget out of the objective function (free CFP model and free budget model).

5. CONCLUSIONS

GP constitutes a suitable tool for designing economically, environmentally and nutritionally sustainable diets. Its flexibility enables specific issues to be studied such as how budget restrictions are linked to the CFP.

The case study shows how an optimal design of the school lunch menus makes it possible to reduce the CFP at affordable prices, demonstrating that trade-offs between the CFP and food budget can be avoided. It also shows that lower food budgets are neither linked to a higher CFP nor to a worse nutritional performance. This fact is evident in several ways: an almost constant budget can be attained for different CFP values and, for a constant CFP, several budget solutions can be found.

These kinds of GP models could be used as a tool with which to select the dishes to be offered in school canteens in order to improve their sustainability. By means of an iterative process, new dishes could be introduced or the existing ones could be modified, providing catering companies with useful information. Specific and very realistic constraints can be included in GP models, such as considering weak constraints on a daily basis, e.g. the sodium content might be around 720 mg, and at the same time strong constraints for the whole planning period e.g. the sodium content has to be lower than 14,400 mg (720 mg x 20 days). Moreover, weak constraints are more suitable for taking micronutrient content into account, since recommendations can slightly vary depending on the source (Cuervo et al. 2009). In the same way, other nutritional recommendations (monounsaturated fatty acids, zinc, folate,...) or nutritional requirements for specific populations (e.g. allergy sufferers, celiacs or religious groups) could be incorporated to the model.

In order to assess the environmental sustainability of diets, other environmental impact categories could be easily added to the model. Nonetheless, the availability of literature on other impact categories is scarcer and the possibility of using site-dependent characterization factors should be taken into account.

The lack of precision in the definition of a sustainable diet makes the task of designing them difficult, and also hampers the measurement of diet sustainability. As Lang (2005) states, nutrition is generally blind to the environment despite the geo-spatial crisis over food supply, which will determine who eats what, when and how. Designing diets by taking into account the environment is a first step to avoid this blindness.

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